Keeyask Generation Project

Environmental Impact Statement

Supporting Volume

Aquatic Environment

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KEEYASK
Hydropower Limited Partnership

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SECTION 2
WATER AND SEDIMENT QUALITY

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2.0 WATER AND SEDIMENT QUALITY

2.1 GENERAL INTRODUCTION

Water quality is an important component of the aquatic environment from the perspective of humans and aquatic life and wildlife that rely upon it. It is important in relation to its use by humans for recreation and as a source for irrigation and drinking water and is also significant from an **aesthetics** perspective.

Sediment quality is also of significance to the health of aquatic biota that live in or on sediments, or that directly or indirectly associate with the sediments and/or benthic communities.

Water quality may be affected by hydroelectric development through a number of pathways. Key pathways include flooding and changes in the water regime (including velocities, volumes, discharge, seasonality, depths, and water residence times). Typical effects of hydroelectric development include increases in nutrients (due to flooding), either increases or decreases in total suspended solids (TSS; due to increased erosion or increased deposition), and decreases in pH and dissolved oxygen (DO) due to flooding. Sediment quality may be affected by hydroelectric development as terrestrial soils are converted to aquatic sediments due to flooding and/or may be altered by changes in sedimentation.

The following sections provide a detailed description of the existing water and sediment quality conditions in the Aquatic Environment Study Area, an overview of historical conditions and temporal changes in the area, and an assessment of the potential effects of the Project on these components.

Specifically, the following provides:

- A description of the approach and methods, including descriptions of information sources, models, and detailed approaches applied for evaluating the environmental setting and for the assessment of effects of the Project on water and sediment quality;
- A description of the environmental setting for water and sediment quality, including an overview of historical information, a detailed description of current conditions, and an assessment of temporal trends; and
- A description of the predicted effects of the Project on water and sediment quality associated with the construction and operation periods, a summary of residual effects, and proposed environmental monitoring and follow-up.

While water and sediment quality are interrelated, for clarity they have been presented in separate sections below. Water quality is discussed in Section 2.2 to Section 2.5 and sediment quality is discussed in Section 2.6.

2.2 WATER QUALITY: INTRODUCTION

Background information describing water quality parameters considered in the assessment is provided in Appendix 2A. Potential effects of the Project on water quality have been considered in terms of its use as a raw drinking water source, its use for recreation, and its importance to the health of aquatic biota and wildlife as set out for various parameters in the Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs, Manitoba Water Stewardship [MWS] 2011) and the Canadian Council for Ministers of the Environment (CCME 1999; updated to 2012). A description of applicable MWQSOGs and CCME guidelines applied for the assessment is provided in Section 2.3.4.1 and a detailed description is provided in Appendix 2B.

2.3 WATER QUALITY: APPROACH AND METHODS

The following sections provide a description of the general approach to the water quality assessment (Section 2.3.1), a brief description of the water quality study area (Section 2.3.2), data and information sources used to describe and characterize the environmental setting (Section 2.3.3), and a description of the approach for the effects assessment (Section 2.3.4).

2.3.1 Overview to Approach

The overall approach taken for the water quality effects assessment was similar to the general approach applied for other aquatic components. The assessment was comprised of two major components:

- A description of the existing water quality conditions in the study area to provide the foundation for assessing the potential effects of the Project on these components; and
- An effects assessment in which potential effects of the Project on water quality were described.

The existing water quality conditions – or the "environmental setting" – were defined for a period of 10 years (1997–2006), supplemented with other more recent published information. This period was identified to capture recent conditions in the study area with sufficient duration to capture inter-annual variability. Information used for this characterization included data gathered from sampling programs conducted over a number of years under the Keeyask environmental studies (*i.e.*, EIS studies), as well as other existing information sources (*e.g.*, primary scientific literature).

To supplement the description of the existing water quality conditions in the study area, an analysis of temporal trends in water quality was undertaken using available literature and data to determine if the current environment is relatively stable or undergoing substantive changes over recent years (*i.e.*, over approximately the last 20 years).

The effects assessment was founded on key linkages identified between the Project and water quality. Information sources used for the assessment included information generated through EIS studies, scientific literature pertaining to hydroelectric development and other reservoirs in Manitoba and elsewhere, use of proxy information (*i.e.*, Stephens Lake), general supporting scientific literature, and modelling. Local knowledge provided by KCNs Members was also considered, where available.

A range of water quality parameters was considered for the study area to address potential effects of the Project on the aquatic environment. The rationale for the inclusion of the various parameters is summarized in Table 2-1. Detailed descriptions of these water quality parameters are provided in Appendix 2A.

Water quality conditions for the existing environment, as well as for predicted post-Project environmental conditions, were compared to MWQSOGs (MWS 2011) and CCME guidelines for the protection of aquatic life (PAL) to assist in characterizing the potential effects of the Project on aquatic biota. As described in detail in Section 2.3.4.1, comparisons were also made to other water usages including drinking water and recreation. However, descriptions of residual effects on drinking water and recreational water quality are provided in the Socio-economic, Resource Use, and Heritage Resources Supporting Volume (SE SV).

2.3.2 Study Area

The water quality study area ranges from the inflows to Split Lake to the Nelson River estuary and includes (see Map 2-1 for main study area and Map 1-4 for access road stream crossing sites):

- <u>The Split Lake area</u>: Split, Clark, and Assean lakes and tributaries to Split Lake (Nelson, Burntwood, and Aiken rivers). Assean Lake is an **off-system** lake that discharges to the Nelson River. The Split Lake area was incorporated into the study area due to Keeyask Cree Nations (KCNs) concerns and because it may serve as an upstream reference area for post-Project monitoring;

- <u>The Keeyask area</u>: the Nelson River from the outlet of Clark Lake to the inflow of Stephens Lake, including small tributaries (Rabbit, Portage, and Two Goose creeks). This area includes the site of the proposed Keeyask Generating Station (GS). The Keeyask area includes the Keeyask reservoir and the upstream portion of the hydraulic zone of influence (HZI);

- <u>The Stephens Lake area</u>: Stephens Lake, including the southern area through which the main flow of the Nelson River passes (the "mainstem") and the northern, more isolated arm of the lake. The Stephens Lake area was included in the study area for several reasons: (1) it includes the downstream portion of the HZI; (2) water quality in Stephens Lake could be affected by the Project (due to upstream effects or effects within this area); and (3) Stephens Lake represents a nearby proxy reservoir and provides empirical information regarding water quality changes over time that assists with the development of the effects assessment for the Keeyask Project;

- <u>The downstream area</u>: the lower Nelson River from Stephens Lake to Gillam Island, including large tributaries (Limestone, Angling, and Weir rivers) and small tributaries (Beaver, Swift, Tiny, and Goose creeks and Creek #15). The downstream area was included to address potential downstream effects of the Project on water quality; and

- <u>Access road stream crossings</u>: stream crossings along the north and south access roads.

2.3.3 Data and Information Sources

Section 1.5 summarizes the overall sources of information used for the Project, including technical studies, scientific publications and local knowledge. Specific sources of information used to characterize the environmental setting for water quality included:

- Local knowledge;
- Pre-1997 studies;
- EIS-specific studies (1999–2006);
- Other studies conducted post-1996; and
- General scientific literature.

Supporting information used for characterizing the existing environment also included:

- Manitoba Water Quality Standards, Objectives, and Guidelines (MWS 2011);
- The CCME environmental quality guidelines (CCME 1999; updated to 2012);
- Health Canada guidelines for Canadian drinking water (Health Canada 2010);
- Health and Welfare Canada guidelines for Canadian recreational water quality (1992); and
- Water quality PAL guidelines from other jurisdictions, where applicable.

2.3.3.1 Pre-1997 Studies

A number of environmental studies were conducted in the study area prior to 1997. These studies primarily focused on the effects of generating stations such as the Limestone GS or Long Spruce GS, or on the effects of Churchill River Diversion (CRD)/Lake Winnipeg Regulation (LWR). The following is a list of the information sources used to describe historical water quality conditions in the study area:

- Schlick (1968) conducted water quality surveys of Split Lake in 1966.
- Crowe (1973) conducted a water chemistry and limnology survey in Split Lake, the Nelson River upstream of the Kelsey GS, and Stephens Lake (Kettle reservoir) in August 1972.
- Underwood McLellan and Associates ([UMA] 1973) described TSS data for Split Lake prior to CRD/LWR.
- Cleugh (1974) described pre-CRD water quality conditions (1972–73) at several sites in the current study area including Split Lake, the lower Nelson River near the Long Spruce GS, and Stephens Lake.
- Penner *et al.* (1975) described sediment loads on the lower Nelson River in 1974 (pre-Limestone and Long Spruce GS).

- MacLaren Plansearch and InterGroup Consultants Ltd (1986) identified several potential issues associated with construction of the Limestone GS that pertain to water quality.
- A limited amount of water quality data were also generated by a series of fisheries studies conducted on the lower Nelson River from 1985–89 during construction of the Limestone GS by Manitoba Fisheries Branch (Swanson 1986; Swanson and Kansas 1987; Swanson *et al.* 1988, 1990, 1991).
- Water quality was evaluated at four sites in Split Lake and three sites in Stephens Lake in 1986 and 1987 under the Manitoba Ecological Monitoring Program (MEMP) and is described in Ramsey *et al.* (1989). Data were also collected in 1988 and 1989 and were presented in Green (1990).
- Water quality data were collected from 1987–1989 in the Split Lake and Aiken River areas as part of the Federal Ecological Monitoring Program (FEMP; Ramsey 1991a).
- Water quality data were collected near the community of Split Lake (in Split Lake) and have been analyzed by several authors (Playle and Williamson 1986; Duncan and Williamson 1988; Playle *et al.* 1988; Ralley and Williamson 1990; Ramsey 1991a; Williamson and Ralley 1993).
- Water quality data were collected from the Kettle, Long Spruce, and Limestone reservoirs and the lower Nelson River as a component of the Limestone Generating Station Monitoring Program in 1989–1994, 1996, 1999, and 2001.
- Local knowledge related to water quality was provided in the Split Lake Post-Project Environmental Review (PPER; Split Lake Cree - Manitoba Hydro Joint Study Group 1996a, b, c).
- Water quality monitoring has been conducted since the 1970s, and continues to be conducted, by Manitoba Conservation and Water Stewardship (MCWS) in Split Lake near the community of Split Lake.

2.3.3.2 Post-1996 Studies

2.3.3.2.1 Keeyask Environmental Studies

Environmental studies to describe water quality in the study area were conducted in 1999 and from 2001 to 2006. The majority of the field studies were completed from 2001 to 2004; additional data were collected in 2005 to 2006 to address information needs and data gaps identified through the course of the Keeyask environmental studies. Additional baseline water quality data were collected in 2009 but are not incorporated into the description of the existing environment. A targeted sampling program was also conducted in fall 2011 to provide baseline data for mercury in water sufficient to address revisions to the MWQSOGs for PAL issued in 2011 (MWS 2011). The results of this 2011 sampling program are summarized in Appendix 2J.

The main water quality study area included the Split Lake/Clark Lake area, including tributaries, Assean Lake, the Nelson River from Clark Lake to Stephens Lake and small tributaries, Gull Lake, and Stephens Lake. Sites were located on the mainstem of the Nelson River, at a number of sites on Split Lake, on tributaries to Split Lake (including the Burntwood, Nelson, and Aiken rivers), on small tributaries between Clark and Stephens Lake (Two Goose Creek, Rabbit Creek, and Portage Creek), two sites on Gull Lake, and at several sites on Stephens Lake (Map 2-2).

Water quality was also measured at a number of sites downstream of Stephens Lake in the open water seasons of 2002–2004 and at accessible sites in the ice-cover seasons of 2003, 2004, and 2006 (Map 2-2). Sites included six locations on the mainstem of the Nelson River, major tributaries (Limestone, Angling, and Weir rivers), and smaller tributaries (Beaver, Swift, Tiny, and Goose creeks and Creek #15; 2004 only).

The water quality component of the Keeyask environmental studies was initiated in 1999, with sampling occurring at three sites in October (one site on the Nelson River below Birthday Rapids and two sites in Gull Lake). In subsequent years, between 17 (2001) and 34 sites (2003) were visited four times in the open water seasons between 2001 and 2004. Approximate sampling times in the open water season were:

- June;
- July;
- Mid-August to early September; and
- Mid-September to early October.

Additionally, water quality was examined at a limited number of sites in winter in 2001–2004; not all sites could be accessed in winter due to logistics and safety issues[1]. A targeted sampling program was conducted in winter 2004, 2005, and 2006 to examine DO conditions in off-current areas under long periods of ice cover (see Appendix 2C for site locations). A focused water quality study was also conducted near the community of York Landing in winter 2007.

Parameters measured included *in situ* variables (DO, pH, turbidity, conductivity, temperature) and a suite of variables measured at a Canadian Association for Laboratory Accreditations, Inc. accredited laboratory, including nutrients, pH, turbidity, TSS, chlorophyll *a* measured at each site and additional variables (total and dissolved metals and major ions, hardness, alkalinity, colour, conductivity, and microbiological parameters) at selected sites. A list of parameters measured in the study area is provided in Appendix 2C.

Water quality was measured at the two stream crossings for the proposed north access road and at three stream crossings along the south access road at various times in 2003–2005. Parameters measured at these sites include *in situ* variables and routine laboratory variables (e.g., nutrients, TSS).

The sampling programs incorporated the collection of Quality Assurance/Quality Control (QA/QC) samples and applied standard measures of QA/QC for sample collection, processing, transport, and data review and evaluation. QA/QC samples included trip and field blanks and triplicate samples.

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[1] Additional sampling was also conducted in 2009 at selected sites but the data have not been incorporated into the environmental setting description.

A detailed description of water quality sampling sites, times, and methods, and data analysis methods is provided in Appendix 2C.

In addition to the water quality studies described above, TSS data were collected from the inlet to Clark Lake to the Kettle GS over the period of 2005–2007 under the Physical Environment Sedimentation baseline studies (Physical Environment Supporting Volume [PE SV], Section 7). DO data were also collected at various sites under the Physical Environment baseline studies, as described in the PE SV, Section 9.

2.3.3.3 Other Information Sources

2.3.3.3.1 Tataskweyak Environmental Monitoring Agency

The Tataskweyak Environmental Monitoring Agency (TEMA) monitoring program included a minimal water quality sampling program. Turbidity was measured (*in situ*) at sediment trap sites during retrieval in October 1998. Secchi disk depths were measured at sediment sampling sites (sediment core sites) in January 1997 and at sediment trap sites in June 1997, June 1998, and October 1998. Additionally, samples of surface water were collected for analysis of TSS at eight sites running along a 450 m transect near the mouth of the Burntwood River in Split Lake in January 1998.

2.3.3.3.2 Manitoba Water Stewardship Water Quality Monitoring

Water quality has been monitored in Split Lake near the community of Split Lake since 1972 and monitoring is currently conducted by MCWS (Map 2-3). Sampling has been conducted three times in the open water season (between June and September) since 2002, but was more frequent prior to 2002. Winter sampling was added at this site beginning in 2010. Raw data, from 1975 to 2006, were provided by MWS (2006) for inclusion in this document. Parameters measured include routine variables (*e.g.*, nutrients, TSS, DO) and metals.

In addition, recent published and unpublished water quality data were compiled with an emphasis on data collected in northern Manitoba to assist in providing context for interpreting EIS water quality data for the study area. This included analysis of data provided by MWS (2006) for the period of 1997–2006 at several sites in northern Manitoba (Table 2-2). Sites included in this analysis (illustrated in Map 2-3) were MCWS water quality monitoring sites at:

- The Burntwood River at Thompson PTH 6 bridge (MB05TGS006);
- The outlet of Sipiwesk Lake (MB05UES001); and
- The Churchill River upstream of Granville Lake (MB06EAS001).

These sites represent three major rivers in northern Manitoba, all of which drain at least in part to the study area. For consistency, only data collected in the open water season were included in the statistical analysis. It is cautioned that data may not be directly comparable to data collected under the Keeyask environmental studies as the sampling frequencies differed.

Monitoring of the Hayes River (downstream of God's River) by Environment Canada (EC) was discontinued in 1996. Therefore, data collected by EC for the period of 1993–1995 (the most recent open water season data available) were summarized. While these data are more than 15 years old, they represent information for a non-regulated river in northern Manitoba and therefore were included to provide context.

2.3.4 Assessment Approach

2.3.4.1 Water Quality Objectives and Guidelines

Provincial water quality objectives and guidelines have been generated for many water quality parameters, for the purpose of protecting aquatic biota and wildlife, and various human usages including recreation, drinking, irrigation, and livestock watering. A summary of relevant water quality objectives and guidelines for the protection of aquatic life, drinking water, and recreation is presented in Appendix 2B. In Manitoba, existing provincial water quality objectives and guidelines were revised in 2011 (MWS 2011) and are largely in accordance with national CCME guidelines (CCME 1999; updated to 2012).

Water quality data were compared to MWQSOGs (MWS 2011) and CCME guidelines (CCME 1999; updated to 2012). Comparisons were made to PAL objectives and guidelines, as well as to drinking water and recreation objectives and guidelines to provide a general context. In addition, guidelines applied by other jurisdictions are discussed where relevant. Comparisons were made to these objectives and guidelines for characterizing the existing conditions as well as for the assessment of Project effects.

In general, water quality objectives and guidelines are more stringent for the protection of aquatic life and wildlife, relative to those established to protect various human usages, including drinking water objectives and guidelines.

2.3.4.1.1 Objectives and Guidelines for the Protection of Aquatic Life

The toxicity of several water quality parameters, including a number of metals and ammonia, is affected by other water quality conditions. For example, several metals are less toxic to aquatic life in hard water than soft water. Consequently, objectives and guidelines for some water quality parameters are calculated based on site-specific interrelated conditions to provide site-specificity. For these parameters, site-specific water quality objectives were calculated, as directed in the MWQSOGs (MWS 2011) and CCME guidelines (CCME 1999; updated to 2012), using the applicable supporting data measured in the same water sample. While the Manitoba narrative guideline for nutrients, which includes a numerical guidelines for total phosphorus (TP), are not specifically applied to the PAL (*i.e.*, the guideline is intended to apply to various uses), it is discussed within MWQSOGs for PAL in this document.

2.3.4.1.2 Drinking Water Quality Objectives and Guidelines

Manitoba and CCME water quality objectives and guidelines for drinking water (MWS 2011) were adopted from the federal Health Canada guidelines (Health Canada 2010) and applicable objectives and guidelines for this study are presented in Appendix 2B. MWQSOGs and CCME guidelines for drinking water are identical.

Drinking water quality objectives and guidelines are intended to be applied to treated or finished water as it emerges from the tap and "are not intended to be applied directly to source waters" (CCME 1999;

updated to 2012). However, comparison of water quality in the study area to drinking water quality objectives and guidelines is included to provide context; it is indicated in the MWQSOGs (MWS 2011) that: "All surface waters…are susceptible to uncontrolled microbiological contamination. It is therefore assumed that all raw surface water supplies will be disinfected as the minimum level of treatment prior to consumption." Health Canada (2011) also "advises that surface water never be consumed without treatment". Furthermore, it is indicated that Manitoba Drinking Water Quality Guidelines "apply to finished drinking water, but can be extrapolated to provide protection to raw drinking water sources"(MWS 2011). As the CCME (1999; updated to 2012) incorporates the Health Canada drinking water quality objectives and guidelines, national drinking water quality guidelines are referred to as "CCME guidelines" in this document.

2.3.4.1.3 Recreational Water Quality Objectives and Guidelines

Manitoba recreational water quality guidelines (MWS 2011) are generally consistent with the Health Canada guidelines (Health and Welfare Canada 1992). The differences relate to guidelines referring to water clarity; Health Canada (Health and Welfare Canada1992) indicates a guideline of 50 NTU (**nephelometric** turbidity units) for turbidity and a Secchi disk depth of 1.2 m while the MWQSOGs indicate a narrative guideline for turbidity. As the CCME (1999; updated to 2012) incorporates the Health Canada recreational water quality guidelines, national recreational water quality guidelines are referred to as "CCME guidelines" in this document.

2.3.4.2 Environmental Setting

The general approach applied for characterizing the existing water quality conditions in the study area involved compilation of existing data and information for the area and the conduct of baseline field studies to generate the information needed to support the impact assessment. Additionally, the environmental setting was detailed for both historic (pre-1997) and recent (1999-2006) time periods. Lastly, evaluation of trends in water quality for the study area was undertaken to ascertain if water quality conditions are notably changing or relatively stable and consistent. Water quality conditions were described and compared to water quality objectives and guidelines.

2.3.4.3 Analysis of Temporal Trends in Water Quality

For the purposes of the environmental assessment, an evaluation of potential temporal changes in water quality within the study area was undertaken to determine if conditions have been undergoing recent change that could in turn affect the impact predictions and/or descriptions of the existing environment based on the period of Keeyask environmental studies. This was addressed through several approaches:

- Statistical analysis of historical water quality data collected in Split Lake for a recent 20 year period;
- Published literature was consulted to assess potential recent temporal changes in water quality in the study area; and
- An assessment of water quality data collected from Stephens Lake and the immediate area since the 1970s (including sites upstream and downstream of the lake).

Methods employed for the statistical analysis of temporal changes in water quality in Split Lake are provided in Appendix 2D. A detailed description of information sources, approach, and results of the temporal analysis of Stephens Lake water quality is presented in Appendix 2E.

2.3.4.4 Project Assessment

Several approaches/information sources were used to describe anticipated effects of the Project on water quality, including:

- Local knowledge;
- Use of empirical information for existing reservoirs in Manitoba, in particular the Stephens Lake reservoir, which was created in 1970;
- Use of information gained from other existing hydroelectric reservoirs, such as reservoirs in Quebec;
- Information gained from the Experimental Lakes Area Reservoir Project (ELARP) in which a boreal reservoir was created by flooding the surrounding peatlands;
- Scientific literature pertaining to Project linkage pathways;
- Information gained from monitoring effects of peat mining and reclamation; and
- Modelling exercises to generate quantitative estimates of potential effects of the Project on water quality.

The assessment relied heavily upon information and predictions generated for other EIS components. In particular, the assessment drew upon information generated from the Physical Environment studies, as described in the PE SV, including:

- Surface Water and Ice Regimes (Section 4);
- Sedimentation (Section 7); and
- Surface Water Temperature and Dissolved Oxygen (Section 9).
- Predicted effects of the Project on water quality were compared to MWQSOGs (MWS 2011) and CCME (1999; updated to 2012) guidelines for the PAL, drinking water, and recreation.

2.3.4.4.1 Description of Modelling Approaches

A description of the modelling undertaken for temperature and DO is provided in the PE SV, Section 9. A description of the modelling undertaken for TSS is provided in the PE SV, Section 7.

Modelling was also used to assist with estimating the potential effects of the Keeyask Project on other water quality variables. Specifically, modelling was employed to estimate:

- The potential effects of increases in metals and nutrients due to peatland erosion and disintegration; and

- The potential effects of leaching and decomposition of flooded peat (*i.e.*, flooding) on nutrients and metals.

A detailed description of the water quality modelling approaches, methods, and results are provided in Appendix 2F. In general, the modelling approaches applied involved mass-balance calculations for key water quality parameters. Effects related to increases in organic TSS, such as increases in nutrients and metals, were estimated using the organic TSS predictions (as presented in the PE SV, Section 7) and information on measured chemistry of peat samples collected in the study area. In addition, the potential contribution of decomposition of flooded organic matter on nutrients and metals in the water column (*i.e.*, benthic nutrient flux) was considered through a mass-balance modelling approach based on the flooded area, peat chemistry, estimates of benthic nutrient/metal flux rates, and water volumes/residence times of the various peat transport zones.

2.3.4.4.2 Characterization of Project Effects

Effects of the Project on water quality were described using the general approach described in Section 1. The general approach used to characterize the effects of the Project on water quality was based on comparison of predicted changes in water quality to MWQSOGs (*i.e.*, is the Project expected to cause an exceedance of a water quality guideline) for the PAL. A detailed description of the characterization of the magnitude of effects of the Project on water quality is provided in Appendix 2G.

2.4 WATER QUALITY: ENVIRONMENTAL SETTING

The following provides a description of water quality for the study area, considering each of the areas described in Section 2.3.2. The discussion provides:

- Local knowledge regarding water quality in the study area;
- An overview of published literature describing water quality changes associated with the CRD/LWR (Section 2.4.1);
- A summary of water quality data collected in the study area under the Keeyask environmental studies since 1997 (Section 2.4.2) as well as an overview of recent water quality data collected at representative northern Manitoba MCWS and EC water quality monitoring sites for regional context. Other published information for the study area collected in this time period was also included; and
- A summary of a statistical temporal analysis conducted on water quality data collected in Split Lake over the period of 1987–2006 and a qualitative temporal analysis of water quality changes in Stephens Lake from 1972 to 2006 (Section 2.4.3).

2.4.1 Pre-1997 Conditions

2.4.1.1 Split Lake Area

Prior to CRD/LWR, water quality surveys were conducted in the Split Lake area in 1966 by Schlick (1968), in 1972 by Crowe (1973), and in 1972 and 1973 by Cleugh (1974). Additionally, TSS data collected prior to 1997 were described by UMA (1973). As part of the Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB) studies, Cleugh (1974) described pre-CRD/LWR water quality conditions (1972-1973) in Split Lake and provided predictions of potential effects of the Project.

Several studies have compared water quality data for Split Lake collected prior to and following CRD/LWR (Vitkin and Penner 1979; Playle and Williamson 1986; Northwest Hydraulic Consultants Ltd. [NHC] 1988; Duncan and Williamson 1988; Playle *et al.* 1988; Ralley and Williamson 1990; Ramsey *et al.* 1989; Ramsey 1991a; Williamson and Ralley 1993). Some of the studies involved statistical analysis (Playle and Williamson 1986; Duncan and Williamson 1988; Playle *et al.* 1988; Ramsey 1991a; Williamson and Ralley 1993), while others qualitatively compared the conditions pre- and post-CRD/LWR (Vitkin and Penner 1979; NHC 1987 and 1988; Ramsey *et al.* 1989; Split Lake Cree - Manitoba Hydro Joint Study Group 1996a, b, c). The results of the individual studies depended largely on the dataset used and how pre- and post-CRD/LWR were defined (*i.e.*, timeline).

Overall, the loading of TSS supplied to Split Lake by the Burntwood River increased post-CRD, although the increases were less than predicted in the LWCNRSB reports. Vitkin and Penner (1979) and NHC (1988) both found that the annual tonnage of sediment delivered to Split Lake increased by a factor of approximately 10 under regulated conditions. However, NHC (1987, 1988) described the effects of CRD on suspended sediments and sedimentation and concluded that: "Sediment concentrations along the CRD [were] not substantially different from pre-diversion concentrations in the Burntwood River…"

Depending on the study, TSS and turbidity in Split Lake have been variously described as increased by CRD/LWR, decreased by CRD/LWR, and unaffected by CRD/LWR. Playle and Williamson (1986) and Playle *et al.* (1988) reported a statistically significant increase in turbidity in Split Lake following CRD/LWR. The analysis was based on a pre- (before mid-1976) and post-CRD/LWR (after mid-1976) comparison of available data collected at a site near the community of Split Lake. Conversely, Williamson and Ralley (1993) reported that turbidity was not statistically different between pre- and several post-CRD/LWR periods evaluated. Ramsey *et al.* (1989) conducted a qualitative comparison of pre-CRD/LWR (1972–73) data to data collected under the MEMP (1986–1987) and concluded that turbidity decreased and transparency increased post-CRD/LWR relative to pre-CRD/LWR conditions. Conversely, based on the results of the FEMP studies, Ramsey (1991a) stated that turbidity, TSS, and transparency did not change in Split Lake after CRD; this was despite the increase in sediment being delivered to the lake. Ramsey (1991a) reported that the lack of increased turbidity in Split Lake could be attributed to significant sediment deposition that was occurring at the mouth of the Burntwood River where it enters Split Lake.

Other changes reported in Split Lake with CRD/LWR include a reduction in colour, major ions, alkalinity, hardness, nitrogen, organic carbon (OC), and conductivity. An initial increase in TP was also observed; however, it was followed by a decline to pre-CRD/LWR levels during the most recent study period evaluated (1987–1992; Williamson and Ralley 1993). Williamson and Ralley (1993) indicated that this may be evidence that the effects of CRD/LWR in Split Lake were stabilizing at that time.

Playle and Williamson (1986) and Playle *et al.* (1988) compared pre- (before mid-1976) and post-Project (after mid-1976) data from a site near the community of Split Lake, and reported significant decreases in conductivity, alkalinity, hardness, calcium, magnesium, sulphate, and total Kjeldahl nitrogen (TKN), and significant increases in total organic carbon (TOC). More recently, Williamson and Ralley (1993) reported similar effects at this site with an expanded dataset (addition of data collected from 1987–1992) and a re-grouping of time periods (1972–75, 1977–84, and 1987–92). The authors of the study also noted a statistically significant reduction in colour, which had not been previously reported.

At the outlet of Split Lake (at a site in Clark Lake) from 1972-73 to 1987, Ramsey (1991a) observed similar changes from 1972–73 to 1987 near the outlet of Split Lake including decreases in: pH; conductivity; hardness; alkalinity; calcium; magnesium; potassium; sodium; chloride; and sulphate. Ramsey (1991a) also reported that extractable iron concentrations in Split Lake increased significantly following CRD/LWR. He attributed this increase to the relatively high concentration of extractable iron in the Burntwood River relative to the Nelson River, combined with the increased contribution of Burntwood River water to Split Lake post-CRD. Ramsey (1991a) concluded that this increase in extractable iron was the only “adverse effect” of CRD/LWR on water chemistry in Split Lake.

The effects of past hydroelectric developments on water quality in the Split Lake Resource Management Area (RMA) were assessed as part of the Split Lake post project evaluation report (PPER) studies on the basis of traditional knowledge and scientific studies (Split Lake Cree - Manitoba Hydro Joint Study Group 1996a, b, c). The document (Split Lake Cree - Manitoba Hydro Joint Study Group 1996a, b, c) stated that: “There is sufficient pre- and post-diversion data on sediment with respect to Split Lake, which generally concludes that the west and north basins of Split Lake and mouth of the Burntwood River are major areas affected by increases in turbidity and sediment deposition”. Traditional knowledge provided in the Split Lake PPER indicated the effects of hydroelectric development included: decreased water clarity and more common occurrences of algae following construction of the Kelsey GS; the Split Lake Cree felt that they could no longer drink the water in the lake and river without feeling they were getting sick following CRD/LWR; and the “flooded shorelines along the diversion route introduced mud, silt, vegetation and wood debris into the waterways and made the water dirtier” (Split Lake Cree - Manitoba Hydro Joint Study Group 1996a).

2.4.1.2 Keeyask Area

No data or assessment of the effects of hydroelectric development on water quality conditions prior to 1997 in the reach of the Nelson River between Clark Lake and Stephens Lake were located in the published literature.

2.4.1.3 Stephens Lake Area

Prior to CRD/LWR, Crowe (1973) conducted a water chemistry and limnology survey in the Nelson River upstream of the Kelsey GS and in Stephens Lake (Kettle reservoir) in August 1972. Comparing conditions in the ‘newly formed’ Kettle reservoir to the older Kelsey reservoir, Crowe (1973) reported that the Kettle reservoir was not stratified and there was evidence of a gradient of DO depletion along flooded areas at depth. As part of the LWCNRSB, Cleugh (1974) described the water quality conditions (1972–73) within the Stephens Lake reach and found that water quality in the north arm of Stephens Lake differed from the mainstem of the Nelson River. Specifically, he reported that dissolved phosphorus (DP), TP, and transparency were higher in the north arm than the mainstem of the lake, and there was DO depletion in the north arm. In addition, while not measured, Cleugh (1974) indicated that the north arm was "highly coloured and dark brown", despite the higher Secchi disk depths observed in this area. Cleugh (1974) attributed the spatial differences to flooding associated with the construction of the Kettle GS and indicated that these "water quality changes are probably typical of what may be expected in inundated areas of most northern reservoirs."

Following CRD/LWR, water quality was evaluated at three sites in Stephens Lake in 1986 and 1987 under the MEMP and the results were qualitatively compared to the pre-CRD/LWR (1972–74) data collected at similar sites in Stephens Lake by the LWCNRSB (Ramsey *et al.* 1989). In the north arm of Stephens Lake, water quality was similar to the main stem in the 1980s (*i.e.*, water transparency and nutrients were lower and total dissolved solids [TDS] were higher than prior to CRD/LWR). These changes were attributed to the evolution of limnological conditions associated with the flooding of the Kettle GS reservoir. The sites compared on the main stem indicated that nutrients, TDS, turbidity, transparency, TSS, conductivity, and colour were in the same range in 1972–74 and 1986–87.

The effects of past hydroelectric developments on water quality in the Split Lake RMA were assessed as part of the Split Lake PPER studies on the basis of local knowledge and scientific studies (Split Lake Cree - Manitoba Hydro Joint Study Group 1996a, b, c). Elders and resource harvesters have stated that water quality in Stephens Lake changed as a result of CRD/LWR and that water quality appeared to further deteriorate around 1984 or 1985. As reported in the Split Lake Cree PPER, Split Lake Cree indicated that turbidity, sediment, and algae were observed to increase in Stephens Lake following CRD and flooding associated with the Kettle GS (Split Lake Cree - Manitoba Hydro Joint Study Group 1996a).

2.4.1.4 Downstream Area

Pre-CRD/LWR, Cleugh (1974) described water quality conditions (1972–73) in the reservoir of the Long Spruce GS and indicated that the Nelson River was "substantially more concentrated…for most chemical constituents" and that "transparency was significantly lower than for the Churchill system".

Within this reach, a number of water quality studies have focused on the effects of GSs such as the Limestone GS or Long Spruce GS. Penner *et al.* (1975) described sediment loads on the lower Nelson River in 1974 (pre-Limestone and Long Spruce GSs) and a limited amount of water quality data were generated by a series of fisheries studies conducted on the lower Nelson River from 1985–89 by Manitoba Fisheries Branch, during construction of the Limestone GS (Swanson 1986; Swanson and Kansas 1987; Swanson *et al.* 1988, 1990, 1991).

Water quality data were also collected from the Long Spruce and Limestone reservoirs and the lower Nelson River as a component of the Limestone Generating Station Monitoring Program in 1989-1994, 1996, and 1999. A synthesis of the effects of the Limestone GS on the aquatic environment by North/South Consultants Inc. (2012) indicated that in general, water quality was fairly consistent between the reservoirs and the downstream sites. Due to the lack of pre-Project data, absolute changes in water quality may have occurred within the Project zone of influence that would not be discernible without baseline data. In addition, some temporary effects may have occurred during and/or immediately following impoundment that were not captured by the program. However, the available information collected post-impoundment in the Limestone reservoir indicates that nutrients were relatively similar to the upstream Long Spruce reservoir and to the downstream environment after impoundment, although interpretation of conditions downstream are more complex due to sampling site relocation and local influences. Similarly, there was no indication that DO was reduced to levels unsuitable for aquatic life in the Limestone reservoir.

Collectively, the post-Project Limestone GS monitoring data, in conjunction with knowledge of the magnitude of flooding and changes in hydrology associated with the Limestone Generation Project indicate that the Project did not result in dramatic nutrient enrichment if at all. Consequently, biotic changes that occurred in the Limestone reservoir were more likely related to changes in water depth and velocity than they were to changes in water quality.

2.4.2 Current Conditions (Post-1996)

The following sections provide a discussion of water quality conditions across the study area as measured since 1997. Information is presented first as an overview of conditions across the study area, with an emphasis on sites sampled on the mainstem of the lower Nelson River and major tributaries (Section 2.4.2.1). Information for variables such as major ions, metals, and microbiological parameters is summarized in Section 2.4.2.1 only. Water quality in the study area is then discussed in a regional context by considering water quality data collected at long-term water quality monitoring sites in northern Manitoba and published literature.

A more detailed discussion of key water quality variables (*i.e.*, nutrients, TDS/conductivity, turbidity, TSS, DO, colour, pH, alkalinity, and hardness) by study area reaches, with an emphasis on results that differ from the overall water quality conditions measured across the study area as a whole, is then presented. Supplemental water quality tables and figures are provided in Appendix 2H. The final section (Section 2.4.3) discusses temporal trends in water quality in Split Lake over the period of 1987–2006 and changes in water quality in Stephens Lake since 1972.

2.4.2.1 Overview

2.4.2.1.1 General Water Quality Conditions

The following is a general overview of water quality conditions measured by Manitoba Hydro during Keeyask environmental studies conducted from Split Lake to the Nelson River estuary from 1999–2006. Means for key water quality variables by site are presented in Table 2-2. Overall, the mainstem of the study area is moderately nutrient-rich (Figure 2-1 and Figure 2-2), well-oxygenated (Figure 2-3), moderately soft to hard (Table 2-2 and Table 2-3), and has a slightly alkaline pH (Figure 2-4). Alkalinity is moderate and is largely owing to the bicarbonate ion, as is typical of Canadian surface waters (Canadian Council of Resource and Environment Ministers [CCREM] 1987). On the basis of alkalinity and pH, the study area would be considered “least sensitive” to acidification and most sites would also be classified as of “least sensitivity” on the basis of calcium concentrations (Table 2-4). Conversely, on the basis of TDS, the sensitivity of waters in the study area ranges from least to moderate.

Water quality is relatively similar across the mainstem of the study area (*i.e.*, along the main flow of the Nelson River to the estuary). However, Split Lake water quality varies near tributary inflows as the quality of water varies between the three main tributaries (the Burntwood, Nelson, and Aiken rivers). The Burntwood River is typically more turbid (Figure 2-5), is characterized by lower alkalinity, TKN (Figure 2-2), TDS/specific conductance (Figure 2-6), is softer (Table 2-2), and contains higher concentrations of TSS (Figure 2-7) and lower fractions of phosphorus in dissolved form (Figure 2-8) than either the Nelson or Aiken rivers or Split Lake proper (*i.e.*, lake outflow). The Nelson River, as it enters Split Lake, has a higher alkalinity and specific conductance/TDS, and is harder than the Burntwood or Aiken rivers. The Aiken River is more coloured, has a lower pH, is clearer, has lower concentrations of TP, and contains higher concentrations of OC and TKN.

Water quality in Stephens Lake also varies spatially. Conditions at the south end of Stephens Lake resemble those observed on the main flow of the Nelson River upstream and downstream of the lake. This area is more nutrient-rich (Figure 2-1 and Figure 2-2), more turbid (Figure 2-5), does not stratify, and is more oxygenated over winter than the north arm of the lake. Like turbidity, TSS concentrations decrease in the southern area of the lake from west to east (Figure 2-7; PE SV, Section 7.3.1.2.1). The north arm may stratify in winter and in summer under atypically low wind conditions. Similarly, DO is lower in the north arm in winter, most notably at depth and in flooded backbays. Temporary depletion of DO at depth can also occur when transient thermal stratification occurs in backbays under low wind conditions.

Changes in some water quality conditions are also evident from Stephens Lake to the estuary. Specifically, TSS (Figure 2-7) and turbidity (Figure 2-5) decrease along the flow of the Nelson River in Stephens Lake and downstream, increasing again at the lower end of the Nelson River (downstream of the Angling River). A similar trend is observed for TP (Figure 2-1). As TP is correlated to TSS (*i.e.*, a significant fraction of the TP is in particulate form; Appendix 2H, Figure 2H-8), this is not unexpected. Other routine variables are generally similar along the length of the lower Nelson River.

Smaller tributaries to the Nelson River (*e.g.*, Two Goose and Beaver creeks) are also typically well-oxygenated (Figure 2-3), relatively clear (low turbidity/TSS; Figure 2-5 and Figure 2-7), and have a near-neutral pH (Figure 2-4). Conductivity (Figure 2-6) and phosphorus (Figure 2-1) are notably lower and OC higher (Figure 2-9) in these streams than the mainstem of the Nelson River. These streams are also somewhat more acidic than the Nelson River (Figure 2-4).

Larger downstream tributaries (Limestone, Angling, and Weir rivers) are generally clearer (Figure 2-5 and Figure 2-7), less phosphorus-rich (Figure 2-1), contain higher concentrations of OC (Figure 2-9), and exhibit lower concentrations of chlorophyll *a* (Figure 2-10) than the mainstem of the Nelson River. The Angling River and, to a lesser extent the Weir River, also tend to be more dilute (*i.e.*, lower conductivity) than the mainstem of the Nelson River (Figure 2-6).

2.4.2.1.2 Comparison of Routine Variables to Water Quality Objectives and Guidelines for the Protection of Aquatic Life

For the purposes of the following discussion, water quality is considered in terms of “routine” water quality variables, major ions and metals, and microbiological parameters. Routine variables include various forms of nutrients, DO, water clarity variables (Secchi disk depth, TSS, turbidity, true colour), pH and alkalinity, hardness, OC, and conductivity and TDS.

Concentrations of ammonia and nitrate/nitrite were consistently below the MWQSOGs and CCME guidelines for the PAL. pH (laboratory and *in situ* measurements) was also within the Manitoba and CCME PAL guidelines (6.5–9) at all sites and times. In general, TP concentrations at lake sites exceeded the MWQSOG narrative guideline of 0.025 milligrams per litre (mg/L) for lakes, whereas mainstem sites and tributaries to the Nelson River were typically below the MWQSOG narrative guideline of 0.050 mg/L for rivers and streams (Figure 2-1).

Dissolved oxygen was consistently within water quality objectives for the protection of aquatic life along the mainstem of the Nelson River in the open water and ice-cover seasons. Conversely, Manitoba water quality objectives and CCME guidelines were not always met at off-current locations. Specifically, several sites in the north arm of Stephens Lake and some sites in the vicinity of York Landing exhibited low DO in winter either across depth or at depth. DO can be lower in winter in ice-covered aquatic ecosystems due to the presence of ice which limits or prevents reaeration and depletion of DO below water quality objectives is relatively common in north-temperate systems in winter. Data collected in summer 2008 also indicated that Manitoba PAL objectives and CCME PAL guidelines for DO may not be met near the sediment-water interface in isolated backbays in Stephens Lake during periods of atypically low wind and subsequent transient stratification.

Additionally, tributaries to the Nelson River downstream of Stephens Lake may exhibit DO concentrations below the most stringent Manitoba objective (for the protection of early life stages of cold water species) and CCME guideline in winter. DO was also below Manitoba water quality objectives and CCME guidelines in the open water and ice-cover seasons at some access road stream crossing sites.

2.4.2.1.3 Comparison of Routine Variables to Drinking Water Quality Guidelines

Nitrate/nitrite was consistently below the Manitoba water quality objective and the CCME guideline for drinking water (10 mg N/L). Conversely, a number of measurements of pH (laboratory and *in situ* measurements) exceeded the upper end of the Manitoba and CCME aesthetic drinking water quality objective (*i.e.*, 8.5). True colour measured in all but one sample collected along the mainstem of the study area (from Split Lake to the estuary) was at or above the Manitoba and CCME aesthetic drinking water quality objective (less than or equal to 15 true colour units [TCU]). As the maximum acceptable concentration (MAC) for turbidity in drinking water is only 0.3/1.0/0.1 NTU (actual limit is dependent upon the method of water treatment), virtually all measurements of turbidity collected throughout the study area exceeded this guideline. However, as indicated in Section 2.3.4.1, it is re-emphasized that drinking water guidelines apply to finished (treated) drinking water, not to raw, untreated water.

2.4.2.1.4 Comparison of Routine Variables to Recreational Water Quality Guidelines

The pH of the study area was consistently within the Manitoba and CCME guideline range for recreation (5–9) and turbidity (laboratory) was typically below the CCME guideline (*i.e.*, Health and Welfare Canada 1992 recreational water quality guideline) of 50 NTU. Three samples collected from Split Lake in July 2003 slightly exceeded the CCME guideline for turbidity. Secchi disk depths are typically less than

1.2 m in the study area and therefore do not currently meet the Health Canada recreational guideline for primary contact recreation waters (*i.e.*, greater than or equal to 1.2 m).

2.4.2.1.5 Trophic Status of the Study Area

Concentrations of TP averaged between 0.03 and 0.04 mg/L at sites located on the mainstem of the Nelson River (Figure 2-1). However, TP declined in Stephens Lake but increased again at the lower end of the Nelson River. Assean Lake and tributaries to the Nelson River contained lower concentrations of phosphorus than the Nelson River. In general, total DP comprises less than half of the TP at sites along the mainstem of the study area, but is more significant in small and large tributaries (Figure 2-8).

On the basis of TP, the mainstem of the study area would be classified as meso-eutrophic to eutrophic, using the CCME phosphorus guidance framework (Table 2-5; CCME 1999; updated to 2012). However, application of trophic categorizations suggested in the scientific literature indicates that on the basis of chlorophyll *a*, the mainstem lakes would be considered mesotrophic. This suggests that factors other than phosphorus (*e.g.*, light) limit algal growth in the area and/or that the bioavailability of phosphorus may be limited. Regression analysis further reveals a weak relationship between chlorophyll *a* and TP concentrations in the study area as a whole (Figure 2H-9). Instead, a significantly positive correlation is observed between TP and TSS (Figure 2H-8), indicating that phosphorus is highly associated with non-algal solids/particulates.

Assean Lake, the north arm of Stephens Lake, small tributaries, the Weir, Angling, Limestone, and Aiken rivers, and sites in Split Lake near the community of York Landing have lower TP concentrations than the mainstem of the Nelson River (Figure 2-1). Trophic status, on the basis of TP, of these sites ranges from oligotrophic (*e.g.*, small tributaries to the lower Nelson River), to mesotrophic (*e.g.*, large tributaries to the lower Nelson River, north arm of Stephens Lake), to meso-eutrophic (*e.g.*, Aiken River).

2.4.2.1.6 Major Ions and Metals

The dominant cations along the Nelson River are calcium and sodium (Figure 2-11). These cations are also dominant in the Burntwood and Aiken rivers, although concentrations of magnesium, potassium, and sodium are lower in these rivers relative to the main flow of the Nelson River (Figure 2-11). Calcium is also notably lower in the Burntwood River than the Nelson River (Figure 2-11).

Of the 28 metals and metalloids analysed in the study area, only beryllium was never detected in surface water samples (Table 2-6). Several metals were either infrequently detected (*i.e.*, less than 10% of samples) or typically present in very low concentrations (*i.e.*, at or near the analytical millilitre [DL]) including antimony, bismuth, cadmium, mercury, selenium, and thallium (Table 2-6; Appendix 2H).

Most metals were consistently below Manitoba and CCME water quality PAL objectives or guidelines, including: arsenic; boron; chromium; lead; molybdenum; nickel; thallium; and uranium (Table 2-7). Several trace elements occasionally exceeded MWQSOGs for the protection of aquatic life including: copper; selenium; and silver. In addition to copper, selenium, and silver, cadmium and zinc occasionally exceeded the CCME PAL guidelines, which are more stringent than the Manitoba PAL water quality objectives (Table 2-7). Chloride was consistently below the CCME PAL guideline (120 mg/L) in all samples collected in the study area (there is currently no MWQSOG for chloride).

The Manitoba water quality guideline for mercury for the PAL was revised from 0.0001 mg/L (as total mercury; Williamson 2002) in July 2011 (MWS 2011). The new guideline refers to inorganic mercury (0.000026 mg/L) and methylmercury (0.000004 mg/L) and is consistent with the CCME PAL guideline (CCME 1999; updated to 2012). The Keeyask environmental studies were initiated prior to issuance of the revised MWQSOGs in 2011 and mercury was analysed at an analytical detection limit that was sufficiently low to facilitate comparisons to the guideline current at that time. Comparison of baseline data for mercury cannot be made where mercury was reported as below the analytical detection limit. However, total mercury was occasionally detected in the study area and when detected the concentrations exceeded the current guideline for inorganic mercury. Thirteen percent of samples collected along the Nelson River system in the open water season contained detectable concentrations of mercury. However, most of these measurements were less than two times the analytical detection limit and should be viewed with caution (i.e., concentrations were near the analytical detection limit).

Additional water quality sampling was conducted in fall 2011 to address the revision to the MWQSOGs for mercury (Appendix 2J). Total mercury, dissolved mercury, and methylmercury were all below the analytical detection limits in samples collected upstream and downstream of the Kelsey GS, Gull Rapids, and the Limestone GS. As the detection limits were below the current MWQSOG and CCME PAL guidelines, these results indicate total mercury and methylmercury concentrations were within the PAL guidelines in the study area.

In addition, Kirk and St. Louis (2009) reported that both total and methylmercury concentrations measured on the lower Nelson River at the Limestone GS from 2003–2007 were low (mean concentrations of total and methylmercury were 0.88 ng/L and 0.05 ng/L, respectively) and all measurements of total mercury and methylmercury were well below the current MWQSOGs and CCME PAL guidelines. The aquatic toxicity of metals is typically related to concentrations of dissolved metals as these are generally the fractions that are bioavailable to aquatic biota. Kirk and St. Louis (2009) reported that most of the total mercury in the Nelson River was in particulate form.

Conversely, the study area is characterized by relatively high concentrations of iron and aluminum, both of which are typically present at concentrations that exceed Manitoba and CCME PAL water quality guidelines (Table 2-7; Figure 2H-10 and Figure 2H-11). Spatially, concentrations of iron and aluminum are relatively similar along the mainstem of the Nelson River from Split Lake to the estuary but are higher in the Burntwood River and notably lower in the Aiken River. Both are relatively abundant elements (iron and aluminum are the third and fourth most abundant elements in the earth's crust, respectively) and elevated concentrations occur in 'pristine' environments, including waterbodies in Manitoba. Ramsey (1991a) concluded that high concentrations of aluminum, copper, and iron in the Burntwood (above Threepoint Lake), Footprint (above Footprint Lake), and Aiken rivers (all "natural, unregulated rivers") were "natural".

High concentrations of iron have occurred since at least the 1970s in Split Lake (Figure 2H-12). Total aluminum has only been recently monitored in Split Lake (beginning in 1998) but concentrations have been consistently above the MWQSOG and CCME PAL guideline (Figure 2H-13). High concentrations of iron have also been reported across Canada and elevated aluminum concentrations have been reported for the western Canada region (Table 2-8).

The mean concentration of total iron measured across the mainstem of the study area is below the recently revised British Columbia Ministry of the Environment (BCMOE) water quality guideline for iron for the protection of aquatic life (1.0 mg/L; BCMOE 2009). Phippen *et al.* (2008) noted that "there is also some evidence that in many circumstances 1 mg/L might be overprotective." The authors also noted that total iron may exceed this guideline due to "natural causes" and that this is often caused by high loads of suspended materials and the association of total iron with suspended materials. Metals may be elevated in association with suspended materials and both total aluminum and total iron are significantly positively correlated to TSS in the study area (Figure 2H-14). Several other metals are also significantly positively correlated to TSS including: barium; chromium; cobalt; manganese; potassium; vanadium; and titanium (Figure 2H-14).

As noted above, the aquatic toxicity of metals is typically related to concentrations of dissolved metals. Dissolved forms of aluminum and iron comprise small fractions of the total forms of each metal in the study area; dissolved aluminum and iron comprised on average 5 and 6% of the total fraction of each metal, respectively[1].

With the exception of two anomalous measurements which are believed to reflect a sampling or measurement error, dissolved aluminum concentrations have been consistently well below the BCMOE (2009) water quality guideline for aluminum which is based on the dissolved form of the metal (0.1 mg/L dissolved aluminum where pH is above 6.5). The BCMOE guideline for dissolved aluminum is the same concentration as the Manitoba (MWS 2011) and CCME (1999; updated to 2012) water quality guideline for total aluminum.

Similarly, with the exception of one anomalous measurement (from the same sample as referred to for aluminum above), dissolved iron has been consistently below the recently revised BCMOE (2009) water quality guideline for dissolved iron for the protection of aquatic life (0.35 mg/L) in the study area. The BCMOE guideline for dissolved iron is 10 times lower than the most sensitive toxicity concentrations identified from the scientific literature (LC50 for *Hyalella* and *Selenastrum*, Phippen *et al.* 2008) and therefore incorporates a safety factor.

PAL water quality objectives and guidelines for metals are typically more stringent than drinking water quality guidelines and most metals were present at concentrations below Manitoba/CCME drinking water quality guidelines[2] across the study area (Table 2H-3). Those parameters that were consistently below Manitoba/CCME drinking water quality guidelines in the study area include: antimony; arsenic; barium; boron; cadmium; chloride; chromium; copper; fluoride; lead; mercury; selenium; sodium; sulphate; uranium; and zinc. The exceptions included: iron (which exceeded the aesthetic objective in the majority [96%] of samples); and manganese in a single sample (which was above the aesthetic guideline).

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[1] Note: Two outliers removed from analysis.

[2] MWQSOGs and CCME drinking water guidelines for metals are identical

2.4.2.1.7 Microbiological Parameters

Fecal coliform bacteria were detected at relatively low concentrations (less than or equal to 40 coliform forming units [CFU]/100 mL) in less than half of the water samples collected over the course of the sampling programs (Table 2H-4). Fecal coliform bacteria were detected across the study area including the Burntwood and Aiken rivers, Split and Stephens lakes, and at various sites along the Nelson River. All measurements were below the Manitoba and CCME water quality guidelines for recreation (200 CFU/100 mL). As the Manitoba/CCME drinking water guideline is 0 CFU/100 mL, where detected, concentrations exceeded the guidelines; however, as indicated in MWS (2011): "All surface waters…are susceptible to uncontrolled microbiological contamination. It is therefore assumed that all raw surface water supplies will be disinfected as the minimum level of treatment prior to consumption."

Cryptosporidium oocysts and *Giardia* cysts (protozoan parasites) were rarely detected in viable forms in the study area (Table 2H-4). Three samples contained a single viable *Cryptosporidium* oocyst (*i.e.*, 1 oocyst/10 L; one sample from the Burntwood River mouth [SPL1] and two samples from the Aiken River [AK1]). Two samples contained a single viable *Giardia* cyst (Split Lake [SPL7] and Stephens Lake [STL1]) and a third sample contained 2 viable cysts (Stephens Lake [STL1]) from 2001–2003. There are currently no numeric Manitoba or CCME guidelines for *Giardia* or *Cryptosporidium* for drinking water, PAL, or recreation.

2.4.2.2 Regional Context

The following is intended to provide a brief description of how water quality in the study area compares to other sites in northern Manitoba to provide a regional context. The comparisons discussed below are not intended to be comprehensive or statistical in nature; rather, the discussion focuses on general qualitative comparisons of key variables.

2.4.2.2.1 Nutrients

The mainstem of the study area is meso-eutrophic to eutrophic on the basis of TP, with concentrations at sites located on the lower portion of the Nelson River generally somewhat lower than sites upstream (Table 2-2). Concentrations are similar to or lower than those measured over the last decade on the Burntwood River and mid-Nelson River system (at Sipiwesk Lake; Table 2-2, Figure 2-1). The higher mean TP concentrations for the Burntwood and Nelson rivers calculated from data provided by MCWS may reflect changes in the analytical laboratory (see Appendix 2D for a more detailed discussion). Phosphorus is lower on the Churchill River at Granville Lake, but the trophic status is consistent with sites on the lower Nelson River. Similarly, Kirk and St. Louis (2009) reported that the Nelson River (at the Limestone GS) contains higher concentrations of TP than the Churchill River (at the river mouth).

To provide a broader context, concentrations of TP measured at sites across Manitoba are depicted in Figure 2-12. TP concentrations in the study area are on the lower end of the range of concentrations measured across the province.

Concentrations of nitrogen (measured as TKN) in the study area are similar to concentrations measured upstream on the Nelson and Burntwood rivers but somewhat higher than concentrations from the Churchill River as measured at Granville Lake (Table 2-2, Figure 2-2). However, Kirk and St. Louis

(2009) reported that relative to a site at the mouth of the Churchill River, total nitrogen (TN) concentrations were lower on the Nelson River than the Churchill River over the period of 2003–2007. Comparison of TN concentrations measured in the study area to other sites in MB indicates that the study area contains relatively low concentrations of nitrogen (Figure 2-13).

2.4.2.2.2 Water Clarity

Water clarity along the mainstem of the study area is lower than the Churchill River (Table 2-2, Figure 2-5 and Figure 2-7). The Burntwood and Nelson rivers are relatively turbid, reflecting the lacustrine clays found in the watersheds (Jones and Armstrong 2001). Bodaly *et al.* (1984a) indicated that lakes along the CRD/LWR route had relatively high turbidities prior to CRD/LWR due at least in part to the **glaciolacustrine** shorelines and sediments, the riverine nature of the lakes, and the shallowness of the lakes. The Nelson River is affected in particular by weathering of fine-grained prairie soils upstream in the watershed.

2.4.2.2.3 Alkalinity/pH

pH and alkalinity are somewhat higher in the study area than in the Churchill River (Table 2-2, Figure 2-4), although pH is within the water quality guidelines for the protection of aquatic life. Total alkalinity is within the typical range for surface waters (*i.e.*, less than 500 mg/L as $CaCO_3$; Table 2-9).

2.4.2.2.4 Total Dissolved Solids/Specific Conductance/Hardness

The Nelson River contains higher concentrations of TDS than the Burntwood, Churchill, or Hayes rivers (Table 2-2). Duncan and Williamson (1988) stated that the Nelson River contains an uncharacteristically high amount of dissolved solids, reflecting the glaciolacustrine clays in the region. However, compared to other large Canadian rivers, the TDS concentrations of the Nelson and Burntwood rivers are moderate (Figure 2-14). The range of TDS observed in the study area lakes is also in agreement with the typical range (100–200 mg/L) for lakes with open-basins (CCREM 1987). Similarly, the Nelson River has harder water than the Burntwood, Churchill, or Hayes rivers (Table 2-2).

2.4.2.2.5 Aluminum and Iron

While relatively high in the study area, concentrations of both aluminum and iron are within the reported ranges for Canadian surface waters and similarly high concentrations are found in undisturbed streams in Manitoba (Ramsey 1991a). Both substances are higher in the Burntwood and Nelson rivers than the Churchill River (Table 2-2). Iron is typically less than 0.5 mg/L in aerated surface waters (CCREM 1987), but ranges up to 7.55 mg/L and 11.0 mg/L in the central and western regions of Canada, respectively (Table 2-8). Aluminum reportedly ranges up to 70 mg/L in Canadian surface waters (CCREM 1987). Jones and Benett (1986) reported that the amount of aluminum in North American rivers ranges from 0.012–2.25 mg/L. In a recent review, Phippen *et al.* (2008) reported that total iron concentrations in freshwater systems can be in excess of 100 mg/L "since the typical analytical techniques would include any suspended soil particles." Concentrations of total iron and aluminum measured in the Red and Assiniboine rivers are notably higher than those recorded in the study area, indicating high concentrations occur in other freshwater rivers in Manitoba (Table 2-10).

2.4.2.2.6 Mercury and Methylmercury

Kirk and St. Louis (2009) reported that the Nelson River (at the Limestone GS) contained significantly lower concentrations of total and methylmercury than the Churchill River (near the Missi Control Structure and at the mouth). Additionally, the authors reported that methylmercury, in particular, was higher in the Churchill River, which they postulated is related to the relatively higher dissolved organic carbon (DOC) concentrations and contributions from wetlands.

2.4.2.3 Split Lake Area

The Split Lake area includes the mouths of the Burntwood, Nelson, and Aiken rivers, and Split, Clark, and Assean lakes (Map 2-4). Split Lake is a relatively shallow lake, with a moderately large surface area (Lawrence *et al.* 1999). It receives flows from the Burntwood River to the west, the upper Nelson River to the southwest, and the Aiken River to the southeast (Map 2-4). Water quality is somewhat heterogeneous in Split Lake, reflecting the locations of multiple tributaries with varying water quality and flows.

Split Lake does not thermally stratify but weak vertical differences in water quality conditions can occur at some locations and times, notably near tributary inflows. Spatially, water quality in the lake resembles the quality of its tributaries near tributary mouths, the extent of which depends upon tributary discharge as well as variability in tributary and lake water quality conditions. Water quality at the Split Lake outlet is a reflection of the various inflows and in-lake processes.

Clark Lake is approximately 11.7 km^2, with average and maximum depths of 5.02 and 23.85 m, respectively, and receives flow from the Assean River, an off-system lake/river system, from the north. Available information indicates Clark Lake does not thermally stratify.

Assean Lake is located to the north of Split and Clark lakes and has a surface area of approximately 77.9 km^2. Thermal stratification has been observed during two spring sampling periods (2001 and 2002), although dissolved oxygen was above 10 mg/L during these periods across depth.

The following provides an overview of key water quality parameters measured over the Keeyask environmental studies in the Split Lake area.

2.4.2.3.1 Dissolved Oxygen

Split, Clark, and Assean lakes and the Burntwood, Nelson, and Aiken rivers are well-oxygenated in the open water season (Figure 2-3) and at most sites in winter (Table 2H-5). DO concentrations were within the Manitoba water quality objectives for cool and cold water aquatic life and CCME guidelines for the protection of cold water aquatic life at most sites and times in the lakes and rivers. Exceptions include DO conditions measured at site SPL5 (near the community of York Landing) in March 2001 and 2004, where DO was less than 9.5 mg/L and a site in Assean Lake in March 2002 where DO was less than 9 mg/L (Table 2H-5). Dissolved oxygen depletion may occur in at least some winters near the Aiken River mouth and the community of York Landing. Sampling conducted at multiple sites in this area in late winter 2007 indicated that DO was typically less than 9.5 mg/L at the surface and decreased across depth reaching 2–4 mg/L at deeper sites (Table 2H-5).

2.4.2.3.2 Turbidity/Total Suspended Solids/Water Clarity/Colour

The Split Lake area is relatively turbid (Figure 2-5) resulting in low transparency (Secchi disk depths less than 1 m). The Burntwood River is more turbid (and has higher TSS concentrations; Figure 2-7) than either the Nelson or Aiken rivers. This is reflected in a more turbid plume emanating from the Burntwood River mouth (Map 2-5). The Aiken River and Assean Lake are notably less turbid and have higher water clarity than Split or Clark lakes and the Burntwood and Nelson rivers. This disparity results in a gradient of turbidity near the Aiken River mouth. True colour is lowest in the Nelson River and highest in the Aiken River.

2.4.2.3.3 pH/Alkalinity

The pH of surface waters in the Split Lake area is somewhat alkaline, typically measuring just above 8, and within MWQSOGs and CCME guidelines for the PAL (6.5–9, Figure 2-4). Alkalinity is moderate in this area, as it is elsewhere in the study area, and is largely owing to the bicarbonate ion. pH is marginally lower in the area in winter, as it is elsewhere along the mainstem of the Nelson River, but remains within MWQSOGs/CCME guidelines for the PAL (Figure 2H-16). pH often decreases in winter in ice-covered systems due to limited photosynthesis (a process that consumes carbon dioxide thus increasing pH) and due to the presence of ice cover which may prevent release of carbon dioxide to the atmosphere. On the basis of alkalinity and pH, the Split Lake area would be considered "least sensitive" to acidification; on the basis of calcium concentration and TDS, waters in the Split Lake area would be considered to have low to moderate acid sensitivity.

2.4.2.3.4 Hardness

Surface water in the Split Lake area is generally 'moderately soft' (hardness 61–120 mg/L; Table 2-2). The Burntwood River is softer than Split and Clark lakes and the Nelson and Aiken rivers and is on the border between "soft" and "moderately soft" classifications (Table 2-2 and Table 2-3). The Nelson River upstream of Split Lake is hard (hardness 121–180 mg/L) and the Aiken River is intermediate between the soft Burntwood River and the hard Nelson River.

2.4.2.3.5 Conductivity/Total Dissolved Solids

Specific conductance and TDS vary notably in the Split Lake area, with the lowest values occurring in the Burntwood River and the highest in the Nelson River; concentrations within Split Lake are intermediate (Figure 2-6). The Aiken River tends to be more dilute than Split Lake, which can be seen as a gradient of increasing conductivity from the river out into the lake (Figure 2H-17). Specific conductance is typically higher in winter than in the open water season in the Split Lake area, as it is elsewhere along the lower Nelson River system (Figure 2H-18).

2.4.2.3.6 Nutrients and Trophic Status

Concentrations of phosphorus (Figure 2-1) and nitrogen (Figure 2-2) are relatively high in the Split Lake area, as they are elsewhere in the study area (Table 2-5). Concentrations of dissolved inorganic nitrogen (DIN) are low but TKN is relatively high. TP is generally above the MWQSOG for lakes, reservoirs, and ponds in Split and Clark lakes but is slightly below this guideline in Assean Lake. Overall, TKN is higher but TP is lower in the Aiken River than other sites in the Split Lake area.

The Aiken River and Assean Lake are mesotrophic/meso-eutrophic whereas Split and Clark lakes and the Nelson and Burntwood rivers are eutrophic on the basis of TP (Table 2-5). However, as indicated in Section 2.4.2.1, the concentrations of chlorophyll *a* are relatively low in the study area and indicate that factors other than TP affect algal growth or that phosphorus bioavailability may be limited.

2.4.2.3.7 Organic Carbon

Concentrations of DOC are generally identical to total organic carbon (TOC) across the study area, averaging approximately 8–9 mg/L. Assean Lake and the Aiken River contain higher concentrations than Split or Clark lakes or the Burntwood or Nelson rivers. DOC and TOC concentrations are similar along the mainstem of the Nelson River (Figure 2-9).

2.4.2.3.8 Spatial Differences in the Split Lake Area

There are several notable spatial differences in water quality across the Split Lake area. The following provides an overview of these differences.

Water quality of the Burntwood River as it enters Split Lake varies from conditions in the upper Nelson or Aiken rivers as well as water quality conditions near the outlet of Split Lake. The Burntwood River is typically more turbid, is characterized by lower alkalinity, TKN, TDS, and specific conductance, is softer, and contains higher concentrations of TSS than either the Nelson or Aiken rivers or Split Lake proper (*e.g.*, lake outflow). The river is also relatively coloured, although less so than the highly tea-coloured Aiken River. Overall the Burntwood River can be characterized as highly-oxygenated, relatively turbid, slightly alkaline, soft, and nutrient-rich. These differences in water quality in the Burntwood River can also be seen, although attenuated, in the Burntwood River plume within Split Lake (site SPL3).

Water quality in the Nelson River (near the mouth) also differs from the Aiken or Burntwood rivers or Split Lake proper (*i.e.*, at the outlet) for some variables. Specifically, the Nelson River is characterized by a higher alkalinity, specific conductance, and concentration of TDS and is harder than Split Lake (outside of the tributary mixing zones) or the Aiken or Burntwood rivers. The Nelson River also contains lower concentrations of iron and aluminum.

The Aiken River, which has a considerably smaller watershed than the Burntwood or Nelson rivers and drains peatlands, exhibits somewhat unique water quality relative to the other waterbodies. The Aiken River is highly coloured, has a lower pH, is clearer (lower turbidity and TSS), and has higher concentrations of TKN, TOC, and DOC and a lower concentration of TP than the Nelson or Burntwood rivers or Split Lake. Water quality variables that are intermediate between the Burntwood River and Split Lake proper include alkalinity, TDS, and hardness. The influence of the Aiken River on water quality in Split Lake can be seen for some parameters (*i.e.*, TKN, TP, TOC, DOC, turbidity) as a gradient in conditions emanating from the river (AK1) into Split Lake (site SPL5 and YL1).

Water quality of Assean Lake is similar to the Aiken River for several parameters; like the Aiken River it is characterized by lower TP, TSS, turbidity, specific conductance, and chlorophyll *a*, but higher TOC, DOC, and transparency (as measured by Secchi disk depth) than Split Lake. Despite differences in water quality of the upstream Assean Lake, water quality at the outlet of Clark Lake is very similar to that observed at the outlet of Split Lake, reflecting the overwhelming dominance of upstream inflows from Split Lake relative to the Assean River system.

2.4.2.4 Keeyask Area

The Keeyask area includes the Nelson River between the outlet of Clark Lake and Stephens Lake, as well as Gull Lake and small tributaries to this reach of the Nelson River (Map 2-6). The following provides a summary of the results of these sampling programs for mainstem and tributary sites separately.

2.4.2.4.1 Mainstem Sites

The following discussion is focused on the results of samples collected at mainstem sites (NR1, NR2, GL1, and GL2) from 2001–2004. In general, water quality conditions in this area are similar to those observed upstream and downstream along the main flow of the Nelson River. A brief overview of the key water quality variables is provided below.

Dissolved Oxygen

The Keeyask area is well-oxygenated in the open water (Figure 2-3) and ice-cover seasons (Table 2H-5), and DO was within MWQSOGs and CCME guidelines for the protection of cool and cold water aquatic life at all sites and times in Gull Lake and the Nelson River mainstem. Concentrations measured under ice in March 2004 at sites on the mainstem (Table 2H-5) and in bays along the north shore of the Nelson River (Map 2-7) were high and well above water quality guidelines/objectives for the protection of aquatic life.

DO concentrations measured in John Garson Bay using a DO data logger in summer 2008 indicate that concentrations remain relatively high overnight and there is no indication of significant diurnal swings (Figure 2H-19); DO concentrations varied typically by less than 1 mg/L over a 24-hour period, being lowest at dawn and peaking at approximately 18:00. Temperature followed a similar diurnal trend. Additionally, DO remained relatively high and at similar concentrations near the surface and bottom of the water column even under periods of low wind (Figure 2H-20); these periods coincided with weak thermal stratification (Figure 2H-21). Although small decreases at depth were observed during these extended calm periods, concentrations were typically above the most stringent MWQSOG for the protection of aquatic life and the CCME PAL guideline for cold water aquatic life and consistently above the Manitoba instantaneous minima at all times.

Turbidity/TSS/Water Clarity

Generally, this reach is relatively turbid (Figure 2-5) with a low transparency (Secchi disk depths less than 1 m). TSS and turbidity measured during the baseline water quality studies did not exhibit substantive spatial variations in the Keeyask area and levels were similar to those measured upstream (Figure 2-5 and Figure 2-7). TSS data collected during the conduct of baseline sedimentation studies indicated similar mean TSS concentrations (means ranged from 13 to 19 mg/L) as measured during the water quality component of the Keeyask environmental studies (means of 15 to 18 mg/L) for the Keeyask area (PE SV, Section 7.3.1.1.1). Similarly, as for most water quality variables, concentrations of TSS vary over time in this and other areas of the Nelson River (PE SV, Section 7.3.1).

pH/Alkalinity

Consistent with other areas of the Nelson River mainstem, pH is typically slightly above 8 in the Keeyask area, indicating slightly alkaline conditions (Figure 2-4). Alkalinity is also similar to other mainstem sites (*i.e.*, less than 100 mg/L as $CaCO_3$) and the area would be classified as "least sensitive" to acidification on the basis of the scheme provided by Saffran and Trew (1996).

Hardness

Waters are generally "moderately soft" (hardness 61–120 mg/L, Table 2-2) in the Keeyask area, as they are upstream, although values slightly higher than 120 mg/L (*i.e.*, "hard" water) have been measured during some sampling periods.

Nutrients and Trophic Status

Concentrations of phosphorus (Figure 2-1) and nitrogen (Figure 2-2) are relatively high in the Keeyask area, as they are elsewhere along the mainstem of the Nelson River in the study area. The mean concentration of TP for sites in the Keeyask area (for the open water season over the period of 2001–2004) ranged between 0.038 and 0.045 mg/L, indicating relatively similar concentrations across this reach (Table 2-5). However, as the MWQSOG narrative guideline for TP varies depending on the type of waterbody (*i.e.*, lake vs. river), some sites exceeded while others met the guideline. Specifically, TP concentrations were above the applicable TP guideline (0.025 mg/L for lakes, reservoirs and ponds and streams/rivers near the point of entry to these waterbodies) in Gull Lake and in the majority of samples collected in the Nelson River near the mouth to Stephens Lake (NR2). Conversely, TP was below the applicable guideline (*i.e.*, 0.050 mg/L) on the Nelson River upstream of Gull Lake (NR1). All sites in the Keeyask area would be classified as eutrophic on the basis of TP (Table 2-5).

Organic Carbon

As observed elsewhere along the mainstem of the study area, DOC and TOC are typically equivalent and concentrations are quite consistent from Split Lake to the estuary (Figure 2-9). Means of TOC along the mainstem of the Nelson River from Clark Lake to the estuary ranged between 8 and 9 mg/L (Table 2-2).

2.4.2.4.2 Tributary Sites

Overall, the water quality of the three small tributaries (Two Goose Creek; Portage Creek; and Rabbit Creek) sampled in this area is similar. The streams are generally well-oxygenated (Figure 2-3) and DO was consistently within the MWQSOGs for the protection of cool and cold water aquatic life and the CCME guideline for cold water aquatic life. The tributaries are also relatively clear, and turbidity (Figure 2-5) and TSS (Figure 2-7) are lower than along the mainstem of the lower Nelson River. Similarly, the specific conductance of the creeks is much lower (approximately half) than that of the mainstem river sites (Figure 2-6). The pH of the tributaries is neutral to slightly alkaline and consistently within the MWQSOGs and CCME guidelines for the PAL (6.5–9.0; Figure 2-4). Nitrogen concentrations are on average similar to concentrations on the mainstem of the Nelson River in Two Goose Creek but were higher on Portage and Rabbit creeks (Figure 2-2). Conversely, phosphorus concentrations are notably lower than the Nelson River and consistently below the Manitoba narrative guideline for streams (0.050 mg/L, Figure 2-1). All three creeks are mesotrophic based on the CCME trophic status categories for TP (Table 2-5).

2.4.2.5 Stephens Lake Area

Stephens Lake is a large lake (surface area approximately 282 km^2) that consists of a relatively riverine southern portion, which carries the main flow of the Nelson River, and an off-current northern arm. Stephens Lake was formed from impoundment of the Nelson River and Moose Lake during creation of the Kettle GS more than 30 years ago. Several small tributaries flow into the northern portion of the lake. The Town of Gillam obtains raw water from the southern shore of Stephens Lake for its municipal system (near sampling site GT1, Map 2-8).

Water quality varies within Stephens Lake as a result of the flow patterns and substrate. Along the main flow of the Nelson River (*i.e.*, the southern portion of the lake), water quality conditions generally resemble those observed on the mainstem upstream and downstream of the lake. This area tends to be more nutrient-rich, does not stratify, and is more oxygenated over winter than the north arm of the lake. Conversely, the northern arm of Stephens Lake can become stratified in winter and areas of low DO concentrations have been observed, most notably over organic substrates or at depth at deeper sites. In extreme instances, complete anoxia may develop in some nearshore areas. Additionally, nutrients are lower and water clarity is higher in the north arm.

TSS (Figure 2-7), turbidity (Figure 2-5), and TP (Figure 2-1) decrease along the main flow of the Nelson River in Stephens Lake. Sedimentation/transport studies have also indicated that settling occurs over this area (PE SV, Section 7), resulting in decreases in TSS. As both turbidity and TP are correlated to TSS in the study area (Figure 2H-8), that similar decreases occur for these parameters would be expected.

2.4.2.5.1 Dissolved Oxygen

Stephens Lake is typically well-oxygenated in the open water season (Figure 2-3), as observed in other areas of the Nelson River system. However, as indicated above, DO depletion is evident in some areas on the northern portion of the lake in at least some winters and concentrations did not meet Manitoba water quality objectives for the protection of cool and cold water species or CCME guidelines for cold water aquatic life in this area (Map 2-9 and Map 2-10). This occurrence is not unexpected due to the presence of long periods of ice cover and lower flow in the off-current north arm of the lake.

Concentrations of DO are also somewhat lower in backbays in the north arm of Stephens Lake in summer, relative to 'offshore' areas and the mainstem in the south. Surveys conducted in August 2005 and 2006 in the vicinity of O'Neil Bay and two sites in the southwestern area of the lake indicate that while DO concentrations at the surface were all above MWQSOGs and CCME guidelines for the PAL, concentrations increased along a gradient emanating from nearshore out into the lake (Figure 2H-23). The offshore site (Site 15, Figure 2H-23) contained similar DO concentrations as the southern sites indicating these conditions are likely restricted to isolated backbay areas, notably in areas of organic substrate.

Data collected with DO loggers in summer 2008 indicated that DO generally remains high and above MWQSOGs for the PAL at the surface in backbays in the north arm of Stephens Lake. However, significant DO depletion may occur at depth during periods of atypically low wind (Figure 2H-24 and Figure 2H-25). Under these atypically low wind speeds temporary thermal stratification may also develop which prevents mixing of the surface and bottom waters (Appendix 2H, Figure 2H-24). When wind speed increased over the period of measurement, DO concentrations were similar at the surface and bottom of the water column indicating that this depletion (and stratification) is relatively atypical and transient. DO concentrations varied by 1 mg/L or less at the surface of the water column over a 24-hour period (Figure 2H-26); temperature similarly varied over a 24-hour period. DO and temperature were generally lowest at approximately 6:00 am.

2.4.2.5.2 Turbidity/ Total Suspended Solids/Water Clarity/Colour

Turbidity is higher along the southern portion of Stephens Lake than the northern arm, but is generally similar to conditions observed upstream and downstream on the mainstem of the Nelson River (Figure 2-5). TSS is also higher in the southern area of the lake, relative to the north arm (Figure 2-7; PE SV, Section 7.3.1.2.1). However, TSS (Figure 2-7) and turbidity (Figure 2-5) decrease along the main flow of the Nelson River in Stephens Lake. This spatial trend was also observed under the sedimentation studies (PE SV, Section 7.3.1.2.1).

Secchi disk depths are less than 1 m in the south end of the lake but water clarity is higher in the north basin, where turbidity and TSS are lower than in the south (Figure 2-5 and Figure 2-7). Backbay areas are also generally less turbid and have lower TSS concentrations (Figure 2H-27 and Figure 2H-28) than off-shore areas on the north arm of Stephens Lake and the southern portion of the lake. Additionally, the depth of the euphotic zone was higher in O'Neil Bay than sites located on the southern mainstem of Stephens Lake in August 2005 and 2006 despite the generally higher concentrations of OC in the backbay (Figure 2H-29).

True colour is similar on the main flow of the Nelson River in Stephens Lake to levels observed upstream and downstream of the lake and levels are at or slightly above the Manitoba and CCME aesthetic drinking water quality guideline of 15 TCU (Table 2-2). True colour is relatively similar in the offshore area in the north arm of Stephens Lake to the southern, mainstem area of the lake (Figure 2H-30). True colour may be somewhat elevated in backbays, most notably in the nearshore areas.

Based on data collected under the water quality component of the Keeyask environmental studies (2001–2004), TSS and turbidity are significantly correlated for the study area as a whole (Figure 2H-22). Secchi disk depth is also significantly correlated to both TSS and turbidity, weakly correlated to TOC, and not correlated to true colour (Figure 2H-31 to Figure 2H-33) for the study area as a whole.

2.4.2.5.3 pH/Alkalinity

The pH of surface waters in Stephens Lake is alkaline, generally ranging just above 8, and within MWQSOGs and CCME guidelines for the protection of aquatic life (6.5–9; Figure 2-4). Alkalinity is moderate in this area as it is elsewhere along the main stem, and is largely owing to the bicarbonate ion. pH is somewhat lower in the area in winter, as it is elsewhere along the mainstem of the Nelson River (Figure 2H-16). On the basis of alkalinity and pH, the south end of Stephens Lake would be considered "least sensitive" to acidification; conversely, on the basis of calcium concentration and TDS, waters in this area would be considered to have low to moderate acid sensitivity (Saffran and Trew 1996). On the basis of pH, the north arm of Stephens Lake would also be classified as "least sensitive" to acidification. pH is somewhat lower in backbay areas relative to offshore in the north arm of Stephens Lake, likely a reflection of the effects of the local drainages (Figure 2H-34).

2.4.2.5.4 Hardness

Surface water in Stephens Lake is 'moderately soft' (hardness 61–120 mg/L; Table 2-2), as observed upstream and downstream on the lower Nelson River.

2.4.2.5.5 Conductivity/Total Dissolved Solids

Specific conductance in the southern area of Stephens Lake is similar to conditions observed at other locations on the mainstem of the Nelson River, but is higher in the north arm of the lake (Figure 2-6; Appendix 2H). As observed elsewhere in the study area, specific conductance is somewhat higher in the ice-cover season (Figure 2H-18). Specific conductance was lower in O'Neil Bay in August 2005 and 2006 relative to offshore sites and the mainstem (Figure 2H-35).

2.4.2.5.6 Nutrients and Trophic Status

Concentrations of phosphorus and nitrogen are relatively high in Stephens Lake, as they are in the lower Nelson River system in general (Table 2-5, Figures 2-1 and 2-2). TP is generally above the MWQSOG for lakes, reservoirs, and ponds (0.025 mg/L) in the southern portion of the lake, along the main flow of the Nelson River, but is below the guideline in the main basin of the north arm of the lake (Table 2-5). Along the mainstem of the river, mean TP concentrations were lower at the southeastern site (STL2) than upstream (STL1); as TP is correlated to TSS (Figure 2H-8), and TSS decreases between these sites, this likely reflects settling of particulate phosphorus.

Similarly, TKN was lower in the north arm of the lake in the open water season of 2004, reflecting generally lower concentrations of nutrients off the main flow of the Nelson River. TKN concentrations may be higher in backbay areas near local inflows (Figure 2H-37).

On the basis of TP concentrations, the south end of Stephens Lake would be classified as meso-eutrophic (southeast) to eutrophic (southwest), as observed for upstream lakes (Table 2-5). Conversely, the north arm of Stephens Lake would be classified as mesotrophic on the basis of TP concentrations measured offshore in 2004 (Table 2-5).

2.4.2.5.7 Organic Carbon

Concentrations of DOC and TOC are effectively equivalent across the study area and both are similar between the offshore area of the north arm of the lake and the southern mainstem (TOC means ranging from 8–9 mg/L; Figure 2-9). However, higher DOC concentrations have been observed in flooded backbays in the north arm of Stephens Lake (Figure 2H-38).

2.4.2.6 Downstream Area

The downstream area includes the Nelson River proper from the outlet of Stephens Lake to Gillam Island, as well as large (Angling, Weir, and Limestone rivers) and small tributaries (Map 2-11). The following provides an overview of the results of the water quality sampling programs for mainstem, major tributary and small tributary sites separately.

2.4.2.6.1 Mainstem Sites

Dissolved Oxygen

The lower Nelson River is well-oxygenated in the open water and ice-cover seasons (Figure 2-3; Table 2H-5), as it is upstream along the mainstem of the river. DO was within the MWQSOGs for the protection of cool and cold water aquatic life and CCME guidelines for cold water aquatic life at all sites and times in the river. There was no evidence of DO depletion in the Limestone reservoir at depth when sampled in September 2004. DO was also high across depth in the Long Spruce and Limestone reservoirs in winter 2006 and there was no evidence of thermal stratification.

Turbidity/TSS/Water Clarity/Colour

In general, the mainstem of the lower Nelson River is relatively turbid (Bodaly *et al*. 1984a) but spatial differences are observed from the Kettle GS to the estuary (Figure 2-5). TSS concentrations decrease in Stephens Lake, as discussed the PE SV, Section 7.3.1.2.1). Downstream of the Kettle GS, there is a further slight decline in the Long Spruce and Limestone reservoirs but both parameters increase as the river approaches the estuary (Figure 2-5 and Figure 2-7). However, overall, mean TSS concentrations remained within a relatively small range in this area over the period of study (2001–2004). Levels of true colour are similar to upstream values and exceed the Manitoba and CCME aesthetic objectives for drinking water (Table 2-2).

pH/Alkalinity

The pH and alkalinity of surface waters in the downstream reach of the Nelson River are similar to upstream. pH is typically above 8 (Figure 2-4) and within MWQSOGs and CCME guidelines for the PAL (6.5–9).

Hardness

Surface water in the downstream reach of the Nelson River is "moderately soft" (hardness 61–120 mg/L), as observed upstream on the main flow of the Nelson River (Table 2-2).

Conductivity/TDS

Specific conductance (Figure 2-6) and TDS in the lower Nelson River are similar to upstream sites on the mainstem (Table 2-2). Specific conductance was slightly higher in winter than the open water season in the two reservoirs, as observed elsewhere in the study area (Figure 2H-18).

Nutrients and Trophic Status

Concentrations of phosphorus (Figure 2-1) and nitrogen (Figure 2-2) are relatively high in the downstream area, as they are in the Nelson River in general. However, during some sampling periods, TP concentrations were notably lower in this area relative to sites upstream on the mainstem (Figure 2-1). Overall, mean concentrations of TP for the open water season are slightly lower than sites in the Split Lake and Keeyask areas (Table 2-5 and Figure 2-1). TP followed a similar spatial pattern as TSS, with decreases observed from Stephens Lake to a site located downstream of the Limestone River (site NR 6), where concentrations again increased. As previously indicated, TP is correlated to TSS which may explain the similar spatial patterns.

Mean TP is below the MWQSOG narrative guideline for streams and rivers (0.05 mg/L) at sites located downstream of the Limestone GS but is above the guideline for lakes reservoirs and ponds (0.025 mg/L) in the reservoirs of the Limestone and Long Spruce GSs. On one occasion (October 2002) TP was above the guideline of 0.05 mg/L at one of the river sites (site NR7 near Deer Island).

Using the CCME TP trophic classifications scheme, with one exception, sites on the lower Nelson River are meso-eutrophic (Table 2-5). The mean TP concentration for the site located near Deer Island (site NR7) for the open water season is slightly higher than other sites and yields a trophic categorization of eutrophic, although the concentration is within the lower end of the range defining this category. Generally, TP concentrations in this area are near the border between meso-eutrophic and eutrophic and are relatively similar.

Organic Carbon

DOC and TOC are very similar and consistent with measurements collected along the mainstem of the Nelson River upstream (Figure 2-9). Like other areas, means of TOC ranged between 8 and 9 mg/L along the lower Nelson River (Table 2-2).

2.4.2.6.2 Major Tributaries

As indicated above, three major tributaries (the Limestone, Angling, and Weir rivers) within the downstream area were sampled during the open water seasons from 2002–2004. Winter sampling was also conducted in the Limestone and Angling rivers in 2003 and 2006. *In situ* measurements were collected from the Weir River in 2003 (the Weir River was inaccessible due to ice conditions in 2006).

Overall, the water quality of these three rivers is similar (Table 2-2). They are generally well- oxygenated (Figure 2-3) and DO exceeded the MWQSOGs for the protection of cool and cold water aquatic life and the CCME guidelines for cold water aquatic life in the open water season. In the ice-cover season of 2003, DO did not meet the Manitoba 7-day average and the instantaneous minimum objectives for cold water aquatic life in the Weir and Angling rivers (Table 2H-5). DO was notably low at the Weir River at this time (3.44 mg/L) and also did not meet the Manitoba 7-day minimum objective for cool water aquatic life or the CCME guidelines for cold water aquatic life (6.5 and 9.5 mg/L). Conversely, DO was high in the Angling River in the ice-cover season of 2006 but was slightly below the most stringent Manitoba objective and CCME guideline (9.5 mg/L) for the protection of cold water aquatic life in the Limestone River at this time. Collectively, these results indicate that the rivers are well-oxygenated in the open water period but may not meet Manitoba water quality objectives or CCME guidelines in some winters.

The Limestone, Angling, and Weir rivers are generally less turbid (Figure 2-5) and contain lower concentrations of TSS (Figure 2-7) than the Nelson River. The pH of the three rivers is alkaline (slightly greater than 8), is consistently within the MWQSOGs and CCME guidelines for the PAL (6.5–9.0), and is similar to the mainstem of the Nelson River (Figure 2-4). Specific conductance is lower in the Weir, and most notably, Angling rivers than the Nelson or Limestone rivers (Figure 2-6). As observed at other sites in the study area, pH is lower and specific conductance is higher in the ice-cover season relative to the open water season (Figure 2H-16 and Figure 2H-18). Nitrogen concentrations in these tributaries are similar to mainstem sites (Figure 2-2) while TOC and DOC are higher in the tributaries (Figure 2-9); however, phosphorus concentrations are notably lower (Figure 2-1) and consistently below the Manitoba narrative guideline for streams and rivers (0.05 mg/L). All three rivers are mesotrophic based on the CCME trophic categorizations for TP (Table 2-5).

2.4.2.6.3 Small Tributaries

Five small tributaries (Map 2-11) within the downstream area were sampled near the mouths during the open water season of 2004 and two were sampled under ice in March 2006 (the remaining streams were dry at the sites accessed). A more intensive survey of conditions in a representative small tributary (Beaver Creek) was conducted in August 2005 and March 2006, evaluating conditions at several sites along the stream.

Overall, the water quality of the creeks is similar (Table 2-2). They are generally well- oxygenated (Figure 2-3) and DO consistently exceeded the MWQSOGs guideline for the protection of cool and cold water aquatic life and the CCME guidelines for cold water aquatic life in the open water season of 2004. DO was also high, and above Manitoba and CCME PAL objectives/guidelines, near the mouths of Beaver and Tiny creeks in winter 2006. However, low DO concentrations (less than 4 mg/L) were observed in Beaver Creek upstream of the Conawapa Road in March 2006.

Turbidity (Figure 2-5) and TSS (Figure 2-7) are low near the creek mouths (*i.e.*, means were below 5 mg/L TSS) and the pH is neutral to slightly alkaline (Figure 2-4). Turbidity, TSS, pH, TP (Figure 2-1), and specific conductance (Figure 2-6) are lower than, TOC and DOC are higher (Figure 2-9) than, and concentrations of nitrogen (Figure 2-2) are similar to, the Nelson River. Specific conductance was higher in Beaver and Tiny creeks in winter than in the open water period and levels in winter were notably higher than mainstem sites sampled in winter 2006. Phosphorus concentrations are low in the small tributary streams and consistently well below the MWQSOG guideline for streams (0.05 mg/L). All five creeks are oligotrophic based on the CCME TP trophic categorization (Table 2-5).

2.4.2.7 Access Road Stream Crossings

Five streams will be crossed by the north and south access roads. The construction of the North Access Road was assessed in the Keeyask Infrastructure Project Environmental Assessment Report (KIP EA). The current assessment considers the operation of the north access road stream crossings and the construction and operation of the South Access Road. Stream crossing locations are illustrated in Figure 1-4.

2.4.2.7.1 North Access Road Stream Crossings

The North Access Road crosses two streams: an unnamed tributary of the South Moswakot River and Looking Back Creek, which flows in to Stephens Lake. As described in the KIP EA, the unnamed tributary will be crossed by a culvert, with rip rap to stabilize the banks on either side. As described in the KIP EA, Looking Back Creek will be crossed by a clear span bridge with no effect on aquatic habitat.

Water quality conditions measured at or near the two stream crossings for the Keeyask north access road indicate moderate concentrations of nutrients (mesotrophic to meso-eutrophic conditions based on TP), higher concentrations of OC but lower levels of specific conductance than the mainstem of the Nelson River, and near-neutral to slightly alkaline pH (Table 2H-6 and Table 2H-7). Stream crossing 2 (on Looking Back Creek) is characterized by higher concentrations of phosphorus than other stream crossings located along the north or south access roads. The unnamed tributary was also clearer than Looking Back Creek (Table 2H-6 and Table 2H-7).

With one exception (sample collected at Looking Back Creek in July 2004), all concentrations of TP were below the Manitoba narrative nutrient guideline for streams (0.05 mg/L; MWS 2011). Ammonia and nitrate/nitrite were consistently below the MWQSOGs and CCME guidelines for the protection of aquatic life and pH was consistently within the Manitoba and CCME PAL guideline range.

Dissolved oxygen conditions varied over the sampling periods at both stream crossings. In the open water season, DO ranged from 3.6 mg/L, which is below the Manitoba instantaneous minimum objective for the protection of early life stages of cool water species and the CCME guidelines for cold water aquatic life, to near saturation. Approximately 12.5% and 38% of DO measurements were below 6.5 mg/L in the open water season (the 30-day MWQSOG and the CCME guideline for mature life stages of cold water aquatic life) at or near the stream crossings at Looking Back Creek and the unnamed tributary, respectively. DO was also below 9.5 mg/L at the unnamed tributary in March and May 2005.

Both areas appear to contain little to no water in winter. The stream crossing on the unnamed tributary was frozen across depth in winter 2009 and the crossing on Looking Back Creek was frozen across depth in winter 2005. In addition, DO concentrations were notably low (1.72 mg/L) at a site approximately 1 km upstream of the crossing on the unnamed tributary in winter 2005.

2.4.2.7.2 South Access Road Stream Crossings

Water quality conditions were generally similar across the three stream crossings for the south access road, as well as generally similar to the crossings for the north access road. Specifically, the crossings were moderately nutrient-rich, had a near-neutral pH, and contained higher concentrations of OC than the mainstem of the Nelson River (Table 2H-6 and Table 2H-7). TSS concentrations were low at stream crossing 3 (Gull Rapids Creek) in the open water seasons of 2003 and 2004, and May 2005 whereas TSS was higher at stream crossing 5 (Gillrat Lake Creek) in May 2005 (note: this site was only sampled in May 2005). As observed along the north access road stream crossings, DO varied across sampling periods on Gull Rapids Creek (ranging from 2.64–10.3 mg/L) and occasionally did not meet the most stringent

Manitoba DO objective and the CCME guideline for aquatic life. Although DO concentrations were above 6.5 mg/L (the most stringent MWQSOG and the CCME guideline for mature life stages of cold water aquatic life) at stream crossing 4 and 5 in May 2005, it is likely that concentrations do on occasion drop below MWQSOGs and/or CCME PAL guidelines in these areas as was observed at other tributaries. Other than DO, other water quality variables (*i.e.*, ammonia, pH, nitrate, and total phosphorus) were within MWQSOGs and CCME guidelines for the PAL.

2.4.3 Current Trends/Future Conditions

For the purposes of the environmental assessment, an evaluation of potential temporal changes in water quality within the study area was undertaken to determine if conditions have been undergoing recent changes that could in turn affect the impact predictions and/or descriptions of the existing environment based on the period of Keeyask environmental studies. This was addressed through several approaches and is summarized below.

2.4.3.1 Statistical Analysis of Water Quality in Split Lake

With the exception of a MCWS monitoring site on Split Lake, there is no long-term record of water quality in the study area that is adequate to facilitate a quantitative analysis of recent temporal trends. As indicated in Section 2.3.3.3, MCWS conducts water quality monitoring in Split Lake near the community. From 2002 to 2009 monitoring was conducted three times during the open water season; sampling in winter was reinitiated in 2010 and sampling frequency varied prior to 2002. These data were obtained from MWS (2006) and subjected to statistical analysis to determine if water quality conditions are generally stable or have changed substantively over a recent 20-year period. This analysis is described in detail in Appendix 2D. The conclusions of this analysis are summarized as follows:

- Comparison of selected water quality parameters between the last two decades (1987–1996 and 1997–2006) revealed that several parameters were significantly higher in the latter decade (TP, TSS, turbidity, specific conductance, alkalinity, hardness, and true colour), while pH was significantly lower.
- Discharges of the two main tributaries to Split Lake (*i.e.*, the Nelson and the Burntwood rivers) were higher in the period of 1997–2006 than the previous decade and discharge of the Nelson River increased more than the Burntwood River over the last decade.
- The observed statistically significant increase in TP and decrease in pH in the latter decade may be artefacts of the use of a new analytical laboratory and not an actual change.
- The observed increase in specific conductance and alkalinity over the last decade may reflect higher river discharges, most notably, the greater proportional contribution of the Nelson River – which is characterized by a higher specific conductance and alkalinity than the Burntwood River. Linear regression analysis indicates a significant influence of the Nelson River discharge on the concentrations of these two parameters in Split Lake.

- Conversely, regression analysis did not demonstrate a significant correlation between turbidity and TSS and the flows of the Burntwood River, Nelson River, or the Burntwood and Nelson rivers combined. Additionally, there is good agreement between measurements of these parameters collected under the Keeyask baselines studies in Split Lake near the community (2001–2004) at similar times as the MWS water quality monitoring, suggesting that inter-laboratory variability was not an issue. However, as described in the PE SV, Appendix 7B, while TSS was weakly correlated to river discharge over the period of 2005–2007, the relationship is complicated by hysteresis (*i.e.*, situation in which the value of one variable [*e.g.*, suspended sediment] depends upon whether the other has been increasing or decreasing [*e.g.*, discharge]).
- The observed increases in true colour and hardness in the most recent decade may be related to changes in river flows. However, the analysis is not conclusive, as linear regression analysis could not be reliably conducted on the data due to failure to comply with statistical assumptions.
- Data for major ions in Split Lake are inadequate to facilitate a comparison of concentrations over a 20-year time frame due to changes in analytical methods; as a result, a shorter time frame was analysed (2001–2003 versus 2004–2006). No statistically significant differences between these time periods were found for chloride, sulphate, calcium, magnesium, sodium, and potassium.
- Similar to major ions, data for metals in Split Lake are inadequate to facilitate a comparison of concentrations over a 20-year time frame due to changes in analytical methods; as a result, a shorter time frame was also evaluated (2001–2003 versus 2004–2006). No statistically significant differences between these time periods were found for most metals including iron and aluminum. Significant differences in concentrations were found for antimony and silicon. Antimony increased from 2001–2003 to 2004–2006; however, as it was only present in trace amounts during both time periods, these results should be viewed with caution. Silicon was lower during the second time period.
- From 1987–2006, most parameters fell within the MWQSOGs (MWS 2011). Exceptions included total iron and aluminum which were consistently above the MWQSOGs, and TP which was often in exceedance of the Manitoba narrative guideline for nutrients (0.025 mg/L) from 1987–2006. Additionally, iron and turbidity consistently exceeded the aesthetic objective and maximum acceptable concentration for drinking water during this same time period. Lastly, true colour was typically above the aesthetic objective for drinking water from 1997–2006, whereas it only occasionally exceeded this objective in the previous decade.

2.4.3.2 Temporal Assessment of Water Quality in Stephens Lake

Stephens Lake (the Kettle reservoir) was created by the construction of the Kettle GS, completed in 1970. Due to its proximity to Keeyask and because the creation of the reservoir involved flooding a substantive area of peatlands, Stephens Lake is used as a proxy to gain additional insight and reduce uncertainties regarding the potential effects of the Keeyask GS on water quality. In general, information gathered on Stephens Lake over time provides a good opportunity to gain an understanding of anticipated effects of the Keeyask GS on the aquatic environment.

Stephens Lake can generally be described as consisting of a southern riverine portion through which the main flow of the Nelson River passes, and a northern arm, which is relatively isolated from the Nelson River flow. Water quality conditions in the flooded northern arm of the lake are used as a proxy for the flooded bays in the Keeyask reservoir and the southern mainstem area of the lake is used as a proxy for the mainstem of the Keeyask reservoir. A qualitative assessment of water quality changes over time in Stephens Lake was conducted to provide this proxy information for the Keeyask effects assessment as well as to describe temporal changes in water quality over time.

A detailed description of the information sources, sampling methods, data comparability, and results of this assessment are provided in Appendix 2E. Briefly, the assessment involved collation of historical information for Stephens Lake as well as sites located upstream and downstream of the lake and qualitatively evaluating changes over time, as well as spatial differences in water quality conditions. The following provides an overview of this assessment.

Absolute changes in water quality conditions in Stephens Lake over the last several decades are difficult to assess for some parameters due to issues associated with varying analytical methods. For this reason, absolute changes in DOC, total dissolved nitrogen (TDN), DP, turbidity, and TSS cannot be determined over this time period. Conversely, analytical methods applied for chlorophyll *a*, pH, TN, Secchi disk depths, and TP appear to be relatively comparable over time. Evaluations of both the absolute changes in these variables over time, as well as relative changes in water quality between the northern and southern areas of the lake, provide insight into the likely effects of the Kettle GS on water quality. Key observations related to water quality in Stephens Lake are summarized as follows:

- In general, water quality conditions in the southern mainstem portion of Stephens Lake have been relatively similar over the period of monitoring (since the early 1970s), as well as to conditions measured concurrently at sites upstream and downstream of the lake. This indicates that water quality has been relatively consistent over several decades and, in particular, that creation of the Kettle reservoir did not have a dramatic effect on the water quality of the mainstem of the Nelson River.
- Conversely, water quality conditions in the north arm of Stephens Lake have changed notably since the early 1970s, likely reflecting the evolution and stabilization of limnological conditions after creation of the reservoir. In general, the available information suggests (noting that pre-project data are not available) that nutrients (notably phosphorus) increased and pH and DO decreased as a result of the Kettle GS. These effects had largely been eliminated by the 1980s (within approximately 15 years post-impoundment).
- There was evidence of some depletion of DO in flooded areas along the southern portion of the reservoir in 1972 and in the north arm in 1972 and 1973. This likely reflected the effects of flooding. Currently, low DO concentrations have been observed in winter in the north arm indicating effects have persisted under ice cover in areas off the main flow of the Nelson River.
- The most dramatic water quality change observed in Stephens Lake over time was the marked reduction in TP and DP in the north arm from the 1970s to the 1980s. Currently concentrations of TP are lower in the north arm than in the southern area of the lake.

- TN was higher in the north arm of the lake in 1972 and 1973 but by the 1980s had become quite similar in the northern and southern areas. In 2004, concentrations were somewhat lower in the north arm. It should be noted, however, that due to analytical changes in TDN measurements, TN may not be directly comparable over time.
- Mean chlorophyll *a* measured in 2004 was lower than in the 1970s and 1980s in the north arm. Concentrations were also lower in 2004 in the north arm relative to the southern mainstem.
- pH was lower in the north arm relative to the southern area of Stephens Lake in 1972 and 1973. In 1987–1989 and 2004, pH was similar in both areas indicating that pH has since increased in the north arm of the lake.
- DOC was higher in the north arm than in the south in 1972 and 1973 and to a lesser extent during some years in the 1980s. In 2004, DOC was quite similar in the north and south areas of Stephens Lake.
- Secchi disk depths in the north arm of the lake appear to have declined since the 1970s. Conversely, Secchi disk depths were relatively similar from 1972–2004 in the southern area of Stephens Lake.
- There are insufficient data to describe changes in turbidity in the north arm over time, relative to southern sites. Conversely, although TSS concentrations cannot be compared over time due to use of different analytical methods, TSS has been lower in the north arm than the southern area of Stephens Lake since 1972.
- True colour appears to have increased in the southern area of Stephens Lake between the 1980s and 2001–2004.

Using TP as the indicator, the trophic status of the north arm of Stephens Lake has changed over time. This area was eutrophic in 1972 and 1973 but shifted to mesotrophic status by the 1980s. Data collected in 2004 indicate that TP in the north arm is very similar to concentrations observed in the 1980s. Effects of construction of the Kettle GS on primary production (as chlorophyll *a*) are less clear; although currently chlorophyll *a* is lower in the north arm relative to the south in Stephens Lake, it is not clear how phytoplankton was altered by creation of the reservoir in the north arm. Although TP concentrations were much higher in the 1970s in the north arm of the lake relative to current conditions and to the southern area of the reservoir in the 1970s, chlorophyll *a* did not follow the same spatio-temporal pattern. This may indicate that primary production was not dramatically or at least consistently affected by the Kettle GS in the north arm of the lake. Increases in DOC may have limited the availability of phosphorus to phytoplankton and/or other factors may have limited phytoplankton growth (*e.g.*, light).

The trophic status of the southern area of Stephens Lake has varied between meso-eutrophic to eutrophic over the last several decades and there is no indication of any progressive trend or change over time. This suggests that either the effects of the creation of the Kettle reservoir on the southern mainstem area of the lake were very short-lived and not captured within the 1972 and 1973 historical studies and/or that the effects were small in the mainstem of the reservoir.

Overall, the available water quality data for Stephens Lake indicate that the north arm of the lake was more acidic and more nutrient-rich (with higher concentrations of DP, TP, TN, and DOC) in the early 1970s relative to more recent years and/or in relation to measurements collected concurrently in the southern area of the lake. This observation is consistent with evolution of limnological conditions in the flooded, isolated area of the lake since the Kettle GS was constructed. Although pre-project data area not available, the temporal changes indicated by the available water quality data, together with scientific knowledge of the temporal changes in water quality following reservoir creation, suggest that the lake experienced an increase in nutrients and a reduction in pH following flooding. Further, the data imply that these effects have either stabilized to pre-project conditions or have in fact departed beyond the pre-project conditions. Some reservoirs may experience nutrient increases in initial years, followed by reductions to concentrations lower than pre-project conditions (*e.g.*, Stockner *et al.* 2000). Regardless, the available information indicates that conditions have notably changed since the 1970s and that the north arm is now considerably more nutrient-poor than the southern mainstem of the lake or the lower Nelson River in general. Collectively, the data indicate that the effects of reservoir creation, most notably flooding, stabilized within approximately 15–20 years post-flood.

In terms of ecological context, water quality conditions in the north arm of Stephens Lake currently resemble those of nearby Assean Lake, whereas water quality of the southern area of the lake resembles the mainstem of the Nelson River.

2.4.3.3 Published Scientific Literature

Jones and Armstrong (2001) conducted a trend analysis for TP and TN at MCWS water quality monitoring sites across Manitoba to determine if either nutrient was significantly increasing or decreasing over the long-term. The analysis indicated no significant trend for flow-adjusted TN concentrations and a significant decreasing trend for flow-adjusted TP concentrations in the Nelson River near Norway House over the period of 1975–1999. The median TP concentration at this site decreased by 20.6% from 1975 to 1999. Similarly, flow-adjusted TP and TN concentrations followed a significant decreasing trend in the Burntwood River at Thompson for the period of 1975–1999. In this instance, the median TP and TN concentrations decreased by 43.8% and 24.1%, respectively.

Manitoba Conservation generated Water Quality Index (WQI) values using the BC WQI for water quality monitoring sites in Manitoba over the period of 1991–1995 (Manitoba Environment 1997). Water quality in Split Lake was ranked as ‘fair’ for the period of 1991–1993 and “good” for 1994 and 1995 (Figure 2-15). WQI values for Split Lake were very similar to those for the Burntwood River at Thompson and somewhat poorer than the Nelson River at Sipiwesk Lake.

The WQI remained relatively uniform, ranging between the boundaries of “fair” and “good”, over this five-year interval for water flowing from Southern Indian Lake (SIL) to Split Lake, indicating that water quality was not changing substantively in space or time (Manitoba Environment 1997). WQI values were more variable between years for sites on the upper Nelson River, which was believed to reflect interannual variations in flow.

2.4.3.4 Water Quality Trends: Synthesis

There is an indication that some water quality variables (true colour, hardness, specific conductance, and alkalinity) have increased in the study area (based on analysis of data collected in Split Lake) between the two periods analysed (1987–1996 vs. 1997–2006) as a result of differences in flows — in particular, the relative contribution of the Burntwood and Nelson rivers to overall discharge. Additionally, there is some indication that several parameters may have changed over the last 20 years in the study area (*e.g.*, TSS and turbidity increased) independent of changes in flows.

A 30-year trend analysis of nutrients in the Burntwood and Nelson rivers indicates that TP and TN are either decreasing in concentration or unchanged, although reasons for these trends are unknown. However, it should be noted that the trend analysis was based on a long period of record and may not reflect more recent trends in nutrients.

Information gathered for an assessment of temporal water quality changes in Stephens Lake indicates that water quality along the mainstem of the Nelson River and in southern Stephens Lake has generally remained consistent over the last several decades. The flooded, north arm of the lake experienced large changes in water quality following impoundment but conditions appear to have been relatively stable since the 1980s.

Overall, the trend analysis information indicates that water quality may vary in the study area in the future in relation to discharges, in particular the relative contribution of the Nelson River versus the Burntwood River to discharge, and that TSS and turbidity may be increasing over time - at least in Split Lake. However, the reasons for these observed increases are not known, making predictions of future conditions difficult. Water quality has been generally stable along the mainstem of the Nelson River in the Keeyask and Stephens Lake areas over the last several decades and conditions appear to have been stable in the north arm of Stephens Lake since the 1980s. Most notably, the occurrence of Manitoba water quality PAL guideline exceedances has been consistent over the last 20 years, indicating that water quality has not notably changed in terms of its suitability to support aquatic life. Based on this information, water quality conditions have been generally stable over the last several decades in the study area, although year-to-year changes may occur in relation to changes in river discharges.

2.5 WATER QUALITY: PROJECT EFFECTS, MITIGATION, AND MONITORING

Assessment of effects on water quality during construction and operation are described below sequentially; for the purposes of the effects assessment, the operation period is defined as beginning with full impoundment (2019), although there will be ongoing construction activities after the first unit is brought into service. Therefore, long-term effects due to flooding are described under operation and effects of actual construction activities are described under construction, even where they will occur after impoundment. However, as discussed in the PE SV, where there is an additive effect (*e.g.*, sediment inputs from erosion of riverbanks due to increased water levels in combination with sediment inputs from cofferdam construction and removal), these are considered together in the construction section.

2.5.1 Construction Period

Major pathways and linkages relating construction activities and potential effects to water quality are presented in Table 2-11. Construction-related pathways considered and described in the following sections in relation to water quality are:

- Construction of instream structures, including placement and removal of cofferdams, excavated materials disposal, barge landings, water intakes, *etc.*;
- Runoff from the access roads, camp site, work areas and other cleared lands (*e.g.*, borrow sites), including potential inputs via groundwater;
- Discharge of treated sewage effluent;
- Blasting;
- Leachate from rock stockpiles and structures containing rock exposed to surface waters/drainage (*e.g.*, dam);
- Discharge of wastewaters from processing of aggregate materials and concrete batch plant, dewatering of cofferdams, water treatment plant filter backwash, dewatering of excavation areas, *etc.*;
- Construction of the south access road; and
- Accidental spills/releases.

There are no linkages between Project construction and potential effects to water quality in Split, Assean, or Clark lakes. The following sub-sections present the assessment of potential effects of construction activities on water quality in the Keeyask area and downstream. A summary of effects of construction on water quality is presented in Table 2-12.

2.5.1.1 Total Suspended Solids, Turbidity, and Water Clarity

There are numerous construction-related activities with the potential to affect concentrations of TSS and related variables (*i.e.*, turbidity and water clarity). Effects described below are focussed upon changes in water quality and potential effects on the protection of aquatic life. Effects of construction activities on drinking water related to water clarity/TSS/turbidity are not discussed for each linkage described below, as the MWQSOGs and CCME guidelines for drinking water indicate a near absence of turbidity (*i.e.*, 0.3/1.0/0.1 NTU, dependent upon water treatment method) and are intended to be applied to treated drinking water. Turbidity is currently well above these guidelines and the exceedances described below will increase with Project construction. Similarly, recreational water quality guidelines relating to water clarity may be exceeded during Project construction, in association with Project-related increases in TSS and are not discussed in detail below.

2.5.1.1.1 Excavated Materials Disposal

Some excavated materials will be placed in-the-dry in areas that will be inundated by the Project. The selection of locations for excavated materials placement areas considered effects to the aquatic environment, and potential locations are presented in the PD SV and Appendix 1A of this document. Excavated materials placement areas that contain fine materials that could become suspended will be capped with appropriate materials to prevent introduction of solids (*i.e.*, TSS) to surface waters (Keeyask GS Environmental Protection Plan [EnvPP]). Therefore, no effects of this construction activity on water quality are expected.

2.5.1.1.2 Cofferdam Placement and Removal

Placement and removal of cofferdams during Stage I and Stage II Diversions have the potential to increase TSS in the Nelson River. The effects of cofferdam placement and removal and concurrent effects related to water diversion and management on TSS in the Nelson River were predicted through modelling exercises and were based on a conservative approach; the methods and results of these modelling exercises are presented in detail in the PE SV, Section 7.4.1. Predicted increases in TSS refer to the fully mixed condition, approximately 1 km downstream of Gull Rapids, for these activities combined and an assessment of these predicted effects on TSS in terms of water quality are described below. A number of sediment and erosion control measures will be undertaken to minimize effects of placement and removal of cofferdams on TSS, as described in the Keeyask GS EnvPP, including:

- Stage I cofferdams will be generally located in areas of the channels with lower velocities;
- Construction designed to prevent erosion due to wave action;
- Construction designed to minimize scour of cofferdams and shorelines due to high flows and velocities;
- Impervious fill will be placed in tranquil water and excavation in the wet will be conducted in tranquil waters, as much as possible;
- If possible, spillway operation will be modified to decrease flows in the vicinity of the work to allow working in-the-dry;
- Different construction techniques will be considered in the event that sediment suspension is noted during rock placement;
- Accumulated sediment and excavated materials will be removed to the furthest extent possible from within the dewatered area before removing a cofferdam;
- Cofferdam material will be removed once it is no longer needed in-the-dry as much as reasonably practical;
- The inner rockfill groin of cofferdams will be removed as much as possible using the outer rock groin for protection from the bulk of flow, which will minimize mobilization of fine material into the river;
- Placement of materials will be controlled by monitoring downstream TSS;
- Activities will be timed to avoid sensitive life stages of fish to the extent possible; and
- Cofferdams will be removed in stages to minimize sediment inputs.

2.5.1.1.3 Impoundment and Diversion during River Management

The PE SV indicates that cofferdam/groin placement, in combination with impoundment and diversion during river management, during the Stage I Diversion will generally result in increases in TSS of less than 5 mg/L above background in the fully mixed lower Nelson River, approximately 1 km downstream of Gull Rapids (PE SV Section 7.4.1.1). These increases are within the long-term MWQSOG and CCME guideline for the PAL (*i.e.*, increases of less than or equal to 5 mg/L above background). The MWQSOG/CCME PAL guideline will be slightly exceeded for approximately six days (maximum predicted increase of 7 mg/L) during placement of the Spillway and Central Dam cofferdams in July 2015.

Placement and removal of cofferdams/groins during Stage II Diversion will occur over three years (2017, 2018, and 2019) during the open water seasons. Most of these activities are predicted to result in increases in TSS of less than 5 mg/L above background, which would be within the MWQSOGs and CCME guidelines for the protection of aquatic life. The exceptions include placement of the South Dam Rock Fill Groin, which is predicted to result in TSS increases of up to 15 mg/L above background, with increases of greater than 5 mg/L for a period of approximately 10 days in early September 2017. An increase in TSS of 7 mg/L for a period one month is also predicted during removal of the Tailrace Summer Level Cofferdam in September/October 2019.

TSS concentrations are predicted to decrease downstream (*i.e.*, downstream of the modelled location, 1 km downstream of Gull Rapids) by approximately 30% prior to reaching the Kettle GS. The majority of this deposition is expected to occur near the entrance to Stephens Lake. TSS would therefore be increased by less than 5 mg/L (typically less than 3 mg/L) during the majority of the instream work associated with cofferdam/groin placement and removal below the Kettle GS. The exception is the maximum predicted increases in TSS, which would occur for the period during the placement of the South Dam Rock Fill Groin in September 2017, when increases may range up to approximately 11 mg/L above background for several days. No measureable deposition of TSS is anticipated downstream of the Kettle GS and these predicted increases in TSS would extend to the estuary. Overall, effects of cofferdam placement and removal on TSS downstream of the Kettle GS are expected to be largely within the MWQSOGs and CCME guidelines for the PAL over the construction period.

2.5.1.1.4 Other Instream Construction Activities

In addition to the major instream construction activities considered above, several activities will be constructed in the wet with the potential to affect TSS in the Nelson River, including: construction of the water intake for the concrete batch plant; several barge landings; the causeway (*i.e.*, installation of a double culvert crossing); and a boat launch upstream and downstream of the GS. Potable water for the construction camp will be obtained from groundwater wells and will therefore not involve instream construction. Sediment and erosion control measures will be employed, as described in the Keeyask GS EnvPP, to minimize effects of these activities on TSS in the river. However, it is assumed that localized increases (i.e., in the immediate vicinity of these construction activities) may result in measureable increases in TSS; negligible effects are expected in the fully mixed river.

2.5.1.1.5 Site Drainage/Runoff

Effects related to site drainage and runoff on TSS in the lower Nelson River and Stephens Lake would be minimized through implementation of sediment and erosion control measures (*e.g.*, maintenance of vegetative **buffer** zones), as outlined in Keeyask GS EnvPP. Stormwater will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations, and permits (Keeyask GS EnvPP). Any sediment-laden water will be directed to adequately sized multi-cell settling pond(s) for treatment prior to release to surface waters (Keeyask GS EnvPP). With mitigation, this pathway is expected to have a negligible effect on TSS concentrations in the lower Nelson River during the construction period.

2.5.1.1.6 Treated Sewage Effluent

Treated sewage effluent from the construction camp will be discharged to the lower Nelson River and effluent quality will meet or exceed the specifications identified in Manitoba *Environment Act* Licence (Licence No. 2952). Effluent would contain TSS at a concentration not to exceed 25 mg/L. The effects of treated sewage effluent on TSS in the lower Nelson River are expected to be negligible in the fully mixed condition; small, localized increases in TSS may occur in the river near the effluent outfall.

2.5.1.1.7 Blasting

It is anticipated that all blasting activities will be conducted in-the-dry and in accordance with Fisheries and Oceans Canada (DFO; formerly known as the Department of Fisheries and Oceans Canada) Blasting guidelines (Wright and Hopky 1998; Keeyask GS EnvPP). Blasting residues (*i.e.*, TSS) may be introduced to surface waters during initial wetting of areas where blasting is conducted (*e.g.*, powerhouse intake channel, spillway approach channel). The effect on TSS in the Nelson River is considered negligible due to the high volume of flow in the river.

2.5.1.1.8 Concrete Batch Plant Effluent and Aggregate Wash Water

Wastewater effluent, including concrete processing wastewater, will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations and permits (Keeyask GS EnvPP). Wastewaters from concrete processing (*i.e.*, concrete batch plant effluent) will be initially discharged to a two-cell settling pond to reduce TSS prior to discharge to the lower Nelson River and apply end-of-pipe discharge criterion of less than 25 mg/L for TSS (Keeyask GS EnvPP). Aggregate wash water will be directed to sediment ponds for treatment (Keeyask GS EnvPP). TSS currently ranges (on average) between 15 and 18 mg/L in the Keeyask area and discharge of the concrete batch plant effluent or aggregate wash water is predicted to cause a negligible change in TSS in the Nelson River.

2.5.1.1.9 Cofferdam Dewatering

Water that is trapped or accumulates behind cofferdams will be discharged to the Nelson River. An end-of-pipe criterion of 25 mg/L will be applied such that where met, water behind cofferdams will be directly released to the Nelson River. Where this target is not met, cofferdam water will be pumped to settling ponds and discharged to the Nelson River when the end-of-pipe TSS concentration is less than

25 mg/L (PDSV, Keeyask GS EnvPP). Effects on TSS in the Nelson River are expected to be negligible in the fully mixed condition; small, localized increases in TSS may occur near these point sources.

2.5.1.1.10 Water Treatment Plant Backwash

Potable water will be supplied to the construction camp using a pre-engineered packaged water treatment plant that will draw water from groundwater wells. Water treatment plant sludge will be disposed of in a landfill and filter backwash wastewater will be discharged to the main channel of the Nelson River. Wastewater effluent, including water treatment plant backwash, will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations and permits (Keeyask GS EnvPP); backwash water would not be discharged to the Nelson River unless TSS was less than 25 mg/L. (Keeyask GS EnvPP). Due to the high discharge of the receiving environment, the effects of backwash wastewater are expected to be negligible in the Nelson River as a whole. A highly localized increase in TSS (*i.e.*, in the immediate area receiving the discharge) may occur during periods of filter backwashing.

2.5.1.1.11 Dewatering of Excavation Areas

Where dewatering of an excavation area is required, the water will be tested and only released to the Nelson River if TSS is less than 25 mg/L. If TSS exceeds this value, water will be treated prior to release (Keeyask GS EnvPP).

2.5.1.1.12 Overall Effects to Total Suspended Solids

The activities with the greatest potential to increase TSS concentrations in the lower Nelson River during construction are related to river impoundment and diversion (*i.e.*, river management) and placement and removal of cofferdams. Other activities considered above are not expected to cause measurable increases in TSS, with the possible exception of localized increases near point sources.

Overall, predicted effects to TSS concentrations during construction would be dominated by the effects related to river diversion and management (*i.e.*, shore erosion) and cofferdam placement and removal. Small (less than 5 mg/L) increases, which will be within MWQSOGs/CCME PAL guidelines, are expected to occur in the fully mixed lower Nelson River 1 km downstream of Gull Rapids. Slightly higher (less than 10 mg/L above the MWQSOGs/CCME PAL guidelines), short-term (days-weeks) increases above the MWQSOGs and CCME guidelines for the protection of aquatic life are predicted during three construction periods, approximately 1 km downstream of Gull Rapids. These exceedances are expected to occur in July 2015, September 2017, and September 2019. TSS concentrations are expected to decrease by 30% in Stephens Lake due to deposition, but the remaining TSS will be carried to the estuary. As modelling was based on the fully mixed condition in the Nelson River and for a site located 1 km downstream of Gull Rapids, it is anticipated that higher concentrations of TSS may occur in the vicinity of construction activities.

2.5.1.2 Dissolved Oxygen

2.5.1.2.1 Impoundment and Diversion during River Management

As discussed at the beginning of Section 2.5, flooding will begin during construction but the effects of reservoir impoundment are discussed in Section 2.5.2.2 below.

2.5.1.2.2 Treated Sewage Effluent

Treated sewage effluent from the construction camp will be discharged to the lower Nelson River and effluent quality will meet or exceed the specifications identified in Manitoba *Environment Act* Licence (Licence No. 2952). Effluent would contain $CBOD_5$ (**carbonaceous biochemical oxygen demand** of a sample incubated at 20°C for five days) at a concentration not to exceed 25 mg/L. The effects of treated sewage effluent on DO in the lower Nelson River are expected to be negligible due to high river discharge, effluent treatment, and high background concentrations of DO.

2.5.1.2.3 Effects on the Ice Regime

The PE SV (Section 4) indicates that ice cover is expected to bridge upstream of Gull Rapids earlier during the winters of Stage I and Stage II Diversion. Under low (1:20 year low winter flows) and high (1:20 year high winter flows) flow conditions, ice bridging will be initiated approximately 3–4 weeks and 6–8 weeks earlier than under current conditions, respectively (PE SV, Section 4.4.1.) Conceptually, extending the duration of ice cover in freshwater ecosystems can increase the magnitude of DO decreases over winter and/or extend the period over which low DO conditions occur. However, as the lower Nelson River is well-oxygenated in winter (at or near saturation) and there is no indication of progressive depletion of DO concentrations along the length of the river, this is not expected to alter concentrations of DO. In addition, as DO concentrations are currently well above the MWQSOGs and CCME guidelines for the PAL, even moderate decreases in DO concentrations (*i.e.*, several mg/L) would not result in concentrations below the MWQSOGs or CCME guidelines.

As described in the PE SV (Section 4.4.1.), the earlier initiation of ice bridging upstream of Gull Rapids (*i.e.*, from downstream of Clark Lake to Gull Rapids) may cause upstream water levels to increase by 0.5–1.5 m during Stage I and Stage II Diversion in the event of a construction design flood (1:20 year high winter flow condition). This occurrence may lead to DO depletion related to decomposition of flooded organic materials similar to that which would occur in the initial period post-impoundment. A detailed assessment of post-impoundment effects is provided in the PE SV, Section 9.4 and in Section 2.5.2.2 below as a component of the operation impact assessment.

2.5.1.3 Nutrients

2.5.1.3.1 Cofferdam Placement and Removal and Impoundment and Diversion during River Management

Nutrient concentrations in the lower Nelson River may be affected by impoundment and river diversion during the construction period. Effects due to reservoir impoundment are discussed in detail in the assessment of operation-related effects in Section 2.5.2.2 below.

Increases in TSS in the Lower Nelson River due to cofferdam/groin placement and removal and water diversion may increase concentrations of TP and TN. The magnitude of these increases would depend on the concentrations of these nutrients in the particulate materials released during these activities. However, given the relatively low increases in TSS predicted during the construction period, effects on nutrients associated are expected to be small. Effects would be greatest in July 2015, September 2017, and September 2019 when TSS is predicted to be greatest.

2.5.1.3.2 Site Drainage/Runoff

As described in Section 2.5.1.1, and detailed in the Keeyask GS EnvPP, stormwater will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations and permits (Keeyask GS EnvPP). Any sediment-laden water will be directed to adequately sized multi-cell settling pond(s) for treatment prior to release to surface waters, and various sediment and erosion control measures will be employed throughout construction to minimize release of sediments to surface waters (Keeyask GS EnvPP). These measures will also minimize release of nutrients to surface waters and the effects on the Nelson River are considered to be negligible. In addition, use of detergents or solvents containing phosphates for cleaning equipment and vehicles will not be permitted (Keeyask GS EnvPP).

2.5.1.3.3 Treated Sewage Effluent

Treated sewage effluent from the construction camp will be discharged to the lower Nelson River. Effluent quality will meet or exceed the specifications identified in Manitoba *Environment Act* Licence (Licence No. 2952) and TP will not exceed 1 mg/L at the end-of-pipe. Effluent would contain unionized ammonia at a concentration not to exceed 1.25 mg/L (at a temperature of 15°C±1°C). The effects of treated sewage effluent on nutrients in the lower Nelson River are expected to be negligible due to high river discharge and effluent treatment; small, localized effects may occur in the immediate vicinity of the outfall prior to full mixing.

2.5.1.3.4 Blasting

It is anticipated that all blasting activities will be conducted in-the-dry and in accordance with DFO Blasting guidelines (Wright and Hopky 1998), and therefore, ammonium nitrate fuel oils (ANFOs) will not be used in or near watercourses/waterbodies. ANFO use will be restricted to areas that will not be subject to contact with surface waters (*i.e.*, powerhouse and spillway structures) to avoid introduction of nitrogenous blasting residues to the aquatic environment. Therefore, blasting conducted during the construction period is not expected to affect ammonia/nitrate in the lower Nelson River.

2.5.1.4 pH and Alkalinity

2.5.1.4.1 Impoundment and Diversion During River Management

As water levels will be increased during construction staging, prior to being increased to full supply level in 2019, effects related to decomposition of flooded terrestrial habitat on water quality will begin during the construction period. pH may decrease in flooded areas, particularly in isolated areas with long water residence times but the effects are expected to be negligible to small and similar to conditions that would occur naturally under high water levels. See Section 2.5.2.2.4 for a detailed description of the effects of reservoir impoundment on pH.

2.5.1.4.2 Treated Sewage Effluent

Treated sewage effluent from the construction camp will be discharged to the lower Nelson River and effluent quality will meet or exceed the specifications identified in Manitoba *Environment Act* Licence (Licence No. 2952). The effects of treated sewage effluent on pH in the lower Nelson River are expected to be negligible in the fully mixed condition due to the high discharge of the Nelson River; small localized effects may occur in the immediate receiving environment.

2.5.1.4.3 Acid Leachate Generation

The potential for rock used to construct the Project (*e.g.*, dykes/cofferdams/main dam) and placed in disposal areas to generate acid leachate, which could subsequently enter the local surface water environment, was assessed through several testing procedures, as discussed in the PE SV, Section 5.4.1.1. With respect to the quarry rock, the assessment concluded that the risk of acidic drainage is low. Analysis of granular material indicated that aluminum, copper, chromium, cadmium, and iron are metals of concern. However, as discussed in Section 5.4.1.1, it is not expected that the use of these materials will pose an environmental concern, although runoff and/or seepage quality may need to be assessed to ensure proper dilutions of the identified metals in the receiving environment.

Based on the results of this testing, no effects on water quality are predicted. Therefore, this linkage is not discussed in subsequent sections.

2.5.1.4.4 Concrete Batch Plant Effluent and Concrete Structures

Wastewaters from concrete processing (*i.e.*, wash water for the concrete aggregate and batch plant) may be alkaline and therefore may increase pH in receiving waters. This potential effect will be mitigated through implementation of appropriate effluent treatment methods if required to maintain pH below 9 (and therefore within MWQSOGs and CCME guidelines for the protection of aquatic life) prior to release to the lower Nelson River. Wastewater effluent, including concrete processing wastewater, will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations and permits (Keeyask GS EnvPP). Liquid concrete will not be allowed to enter a watercourse, and storage, mixing and placing of concrete and grouting structures will be undertaken in the contractor work area or within the cofferdam, or at least 100 m from the Nelson River or tributary streams (Keeyask GS EnvPP). With mitigation, these activities are not expected to cause a measurable change in pH in the Nelson River due to the high river discharge and the existing buffering capacity of the river. Therefore, negligible effects on pH are expected.

2.5.1.5 Bacteria and Parasites

2.5.1.5.1 Treated Sewage Effluent

Treated sewage effluent from the construction camp will be discharged to the lower Nelson River and effluent quality will meet or exceed the specifications identified in Manitoba *Environment Act* Licence (Licence No. 2952). Effluent would contain total coliform bacteria and fecal coliform bacteria at concentrations not to exceed 1500 and 200 MPN/100 mL, respectively. The effects of treated sewage effluent on coliform bacteria in the lower Nelson River are expected to be negligible due to high river discharge and effluent treatment.

2.5.1.6 Metals and Contaminants

2.5.1.6.1 Cofferdam Placement and Removal and Impoundment and Diversion During River Management

Metals will be introduced into the aquatic environment in association with construction activities that release sediments, as discussed above. Given the relatively small predicted increases in TSS during construction, effects on metals are expected to be negligible to small. Effects would be greatest in July 2015, September 2017, and September 2019 when TSS is predicted to be highest.

2.5.1.6.2 Site Runoff/Drainage

Site runoff and drainage, including water used for machinery, equipment and vehicle washing, may contain elevated levels of metals and other contaminants (*e.g.*, hydrocarbons) associated with use of heavy equipment and vehicles. Measures will be implemented to mitigate effects of site construction activities on the introduction of sediment to the lower Nelson River through implementation of a various sediment and erosion control measures as described in the Keeyask GS EnvPP. Water used for cleaning of vehicles, equipment, and machinery at site will be contained and treated prior to release (Keeyask GS EnvPP). Wastewater effluent, including stormwater, will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations, and permits (Keeyask GS EnvPP). These mitigation measures will minimize both the introduction of sediment and associated metals and hydrocarbons to surface waters.

2.5.1.6.3 Cofferdam Seepage

During construction, water with elevated levels of contaminants may accumulate within the cofferdams due to runoff and seepage in conjunction with the use of heavy equipment. The PD SV indicates that seepage waters that collect behind cofferdams may be routed to the settling ponds receiving concrete batch plant effluent to reduce TSS. This water will also be tested and treated, if required, prior to discharge to the Nelson River.

2.5.1.6.4 Water Treatment Plant Backwash

Potable water will be supplied to the construction camp using a pre-engineered packaged water treatment plant that will draw water from groundwater wells. Water treatment plant sludge will be disposed of in a landfill and filter backwash wastewater will be discharged to the main channel of the Nelson River. Backwash wastewater may contain higher concentrations of some metals than the Nelson River but due to the high discharge of the receiving environment, the effects of this discharge are expected to be negligible in the Nelson River as a whole. Wastewater effluent, including water treatment plant backwash, will not be directly released to a waterbody unless it has been treated to meet applicable provincial and federal effluent licences, authorizations and permits (Keeyask GS EnvPP). A highly localized increase in some metals (*i.e.*, in the immediate area receiving the discharge) may occur during periods of filter backwashing.

2.5.1.6.5 Accidental Spills/Releases

The presence and levels of hydrocarbons in the local surface water environment could potentially be affected by accidental spills or releases of substances containing hydrocarbons (*e.g.*, fossil fuels) or other contaminants.

The release of significant quantities of hazardous substances to the aquatic environment as a result of accidental spills and releases is considered unlikely due to the development and implementation of good management practices, including:

- Handling and storage of materials in accordance with established policies and regulations;
- Transportation of dangerous goods as required by legislation/regulation; and
- Having spill response programs and equipment in place to address spillage or oils or other contaminants.

As discussed in the Physical Environment SV Section 8.4.1, due to the shallow nature of the groundwater in most areas, there is a risk of groundwater contamination from an accidental event such as a fuel spill. Contaminated groundwater could eventually flow into surface waters. However, this effect will be mitigated through measures such as the siting of refuelling areas. A Project-Specific Emergency Response Plan including prevention and planning and response for hazardous material spills by the contractor, as described in the Keeyask GS EnvPP. Various environmental protection measures for the management of hazardous materials and petroleum products will be applied, as described in the Keeyask GS EnvPP.

2.5.1.7 Assessment of Construction-Related Effects: South Access Road

Construction of the south access road will involve installation of three culverts as well as clearing the road right-of-way (Map 1-4). The principal impact to water quality related to these activities is the input of sediments into natural watercourses. These potential effects would be mitigated through procedures described in the “Manitoba Stream Crossing Guidelines for Protection of Fish and Fish Habitat” (DFO and Manitoba Natural Resources 1996) and through measures described in the Keeyask South Access Road EnvPP, including, but not limited to, the following:

- A 30 m buffer zone of low vegetation from the ordinary high water mark will be maintained at the stream crossings until immediately prior to construction of the crossings;
- Stream crossings will be constructed in the winter, where possible;
- Stream crossings will be constructed in-the-dry through isolation of the work area, should construction occur when the stream is flowing;
- A 100 m vegetated buffer will be maintained adjacent to lakes, streams, wetlands, and riparian areas, wherever possible;
- Wherever possible, clearing will be minimized to reduce the exposure of bare ground;

- Construction will be designed and executed to prevent the release or settling of any sediment outside of construction boundaries;
- In steeply sloped areas susceptible to erosion, runoff will be directed away from disturbed areas to prevent further site degradation;
- Disturbed areas will be stabilized, vegetated and/or seeded as soon as possible following construction;
- Accumulated sediment will be removed from silt fences, check dams, straw bales, *etc.* at regular intervals to ensure proper function;
- Erosion and sediment control measures will be maintained until either natural vegetation or permanent measures are established to prevent further erosion or sediment loss;
- Additional measures will be implemented, if required, to protect permafrost areas from extreme runoff events during periods of heavy precipitation or melt;
- Installation of appropriately sized and positioned culverts to pass flows;
- Drill cuttings, solid waste or any other untreated effluent will not be released where it may enter a watercourse/body;
- Banks where work occurs close to the shoreline will be stabilized so that bank erosion and downstream sedimentation is avoided;
- All spoil piles will be stabilized, including covering spoil piles with biodegradable mats or tarps will be maintained until disturbed areas or spoil piles are successfully reclaimed;
- Sediment laden runoff from roadside ditches or from the approaches to the crossings will be prevented from entering the watercourse/body;
- All new channels or banks will be stabilized against erosion by using rock, geotechnical fabric, seeding, mulching or a combination of these;
- Disturbed stream banks will be restored, where possible;
- Borrow pits will not be located within 100 m of a watercourse/body, wetland or steep slopes;
- Should a temporary camp be required for the construction of the South Access Road, potable water will be trucked to site and wastewater will be collected and hauled off site for disposal at a licensed wastewater facility; and
- Riprap and fill material placed adjacent to watercourses will be clean and free of fine material.

As a result of application of the various mitigation measures (see the Keeyask South Access Road EnvPP for additional details), effects to water quality are expected to be negligible.

2.5.2 Operation Period

Hydroelectric development often results in changes in water quality, although the magnitude, extent, and duration of these changes may vary considerably between systems. In general, hydroelectric development may affect water quality in the reservoir itself and/or water quality in the downstream environment. Common water quality changes observed in new reservoirs are:

- Increases in nutrients due to flooding and decomposition of terrestrial organic materials;
- Decreases in pH due to flooding;
- Increases in TSS due to increased shoreline erosion or decreases in TSS due to changes in the water regime;
- Decreases in DO due to flooding and decomposition of terrestrial organic materials;
- Increases in total dissolved gas pressure due to entrainment of gas bubbles into spilled water; and
- The downstream environment may be affected through changes in upstream water quality and/or due to effects of alterations in the water regime (*e.g.*, increased downstream erosion due to alterations in the water regime).

The Keeyask Project may affect water quality during the operation period through a number of pathways. Linkages between the Project operation and water quality are presented in Table 2-1 and illustrated in Figure 2-16. In brief, water quality may be affected by the Project during the operation period through a number of pathways including:

- Changes in the water regime: changes in water levels, flows, velocities, depths, and residence times may affect mixing, reaeration, accumulation, cycling or losses of substances from the reservoir, and thermal regimes;
- Changes in the ice regime: changes in the spatial extent of open water areas and/or timing of freeze-up and break-up may affect reaeration (and therefore DO concentrations) and/or light availability;
- Flooding of terrestrial habitat: decomposition of flooded organic materials may affect DO, pH, nutrients (phosphorus and nitrogen), OC, colour, and/or metals; and
- Erosion and sediment transport/deposition: hydroelectric development often increases shoreline erosion thereby affecting TSS and water clarity, but may also lead to enhanced sedimentation associated with reductions in velocities.

The key water quality variables commonly altered by hydroelectric developments are:

- Nutrients, including phosphorus and nitrogen;
- Dissolved oxygen;
- pH; and
- TSS/turbidity/water clarity.

Other parameters may be altered including metals (including mercury), conductivity/TDS, OC, and colour. Effects of the Project operation on water temperature and dissolved oxygen are described in detail in the PE SV, Section 9 and effects of the Project on sedimentation are described in detail in the PE SV, Section 7. This information is also summarized below to describe overall effects on water quality.

2.5.2.1 Split Lake Area

Effects of the Keeyask Project on Split Lake are limited to the possibility that under low flow conditions (which occur on average once every 20 years) peak winter water levels on Split Lake could be increased up to 0.2 m above those that would occur without the Project (PE SV, Section 4.4.2.4). However, should this happen, "resulting winter water levels would still be well within the range of winter levels experienced in the existing environment on Split Lake since CRD and LWR have been in operation." (PE SV, Section 4.4.2.4). Therefore, no effects to water quality in Split Lake as a result of the operation of the Project are predicted.

2.5.2.2 Keeyask Area

In general, the Keeyask area extends from the outlet of Clark Lake to the Keeyask GS and includes the reservoir proper. The HZI of the Keeyask Project extends from a point approximately 40 km upstream of the GS to 3 km downstream of the GS (PE SV, Section 4.4.2.2 and Section 4.4.2.3). Downstream effects to water quality are discussed in subsequent sections, except for effects on total dissolved gas pressure.

As indicated in Section 2.5.2, water quality in the Keeyask area may be affected by a number of pathways during the operation period, including changes in the water regime, flooding, and erosion/sedimentation. The following provides a description of predicted effects to water quality by parameter for this area; effects are expected to vary spatially across the reservoir in relation to water depth, mixing/water residence times, and velocities.

In general, water quality effects are described in the following sections based on the distinctions between nearshore, flooded bays (**lentic** environments) and the deeper, **lotic** areas of the reservoir, as defined in Section 3.4.2.2. Distinctions are also made on the basis of depth; "shallow" refers to depths of 0–3 m; and "deep" refers to depths greater than 3 m. Lotic areas, which are composed largely of deep habitat, within the lacustrine portion of the reservoir are also referred to as "mainstem". Water quality parameters discussed below include water temperature, DO, pH, TSS/turbidity, OC, true colour, water clarity, nutrients (nitrogen and phosphorus), conductivity/TDS, and metals.

2.5.2.2.1 Water Temperature

Currently the mainstem of the study area does not thermally stratify but off-current areas may weakly stratify during infrequent periods of very low wind (PE SV, Section 9). The reservoir is not expected to thermally stratify along the mainstem but may stratify in lentic, off-current areas in winter and during low wind periods in summer (PE SV, Section 9.4.2.1). Water temperatures of lentic areas are expected to more closely mirror ambient air temperatures than the larger mainstem area of the reservoir. In addition, increases in dissolved organic matter, which are expected in lentic areas over flooded terrestrial habitat, may increase the temperature of the upper 1 m of water, due to effects of the humic acids on light absorption (notably ultraviolet radiation; Wetzel 1983).

2.5.2.2.2 Dissolved Oxygen

Dissolved oxygen is commonly affected by reservoir creation due to the introduction and subsequent decomposition of flooded organic materials and is generally most affected in nearshore, flooded habitats (*e.g.*, Paterson *et al.* 1997). Lower DO concentrations have been observed in northern Manitoba reservoirs (*e.g.*, Notigi Lake: Hecky *et al.* 1987a; Stephens Lake: Cleugh 1974, Crowe 1973) and Quebec reservoirs (*e.g.*, Hayeur 2001) following flooding. In addition, DO may be affected by alterations in the thermal regime (*e.g.*, should stratification be created), the ice regime (*i.e.*, changes in the timing of freeze-up and break-up and/or the extent and duration of open water areas in winter that in turn affect reaeration), the water regime (*e.g.*, changes in water residence times, water depths, mixing, turbulence), and erosion of organic shoreline materials (*e.g.*, introduction of organic materials from shoreline erosion may increase the oxygen demand in water).

Information collected from reservoirs in Manitoba indicates that the magnitude and duration of effects to DO are variable. For example, no effects to DO were reported for SIL post- CRD, which was postulated to be a result of the large volume of the lake, rapid mixing and large **fetches** (Hecky *et al.* 1987a). This occurred despite observed decreases in DO in **limnocorral** experiments in which organic materials, including moss/peat, were added to SIL surface waters (Hecky *et al.* 1987a). Conversely, decreases in DO were observed in both the east and west basins of Notigi Lake during and following reservoir filling (Bodaly *et al.* 1984a; Hecky *et al.* 1987a). Anoxic conditions were reached at depth during the filling period and reduced DO conditions persisted for a number of years following flooding and diversion. The observed differences regarding effects of impoundment on DO between SIL and Notigi Lake likely reflects differences in hydrology, areas of flooding, lake morphometries, and limnology (*e.g.*, depths and stratification).

The following provides a brief overview of the results of the DO modelling exercises described in the PE SV, Section 9, a discussion of other linkages between the Project operation and DO (*e.g.*, phytoplankton), consideration of changes in the ice regime outside of the modelled area, site-specific considerations relevant to resident biota, and consideration of Manitoba PAL water quality objectives and CCME PAL guidelines for DO. The DO assessment was also based on information collected from Stephens Lake and other reservoirs in Manitoba, reservoirs in other areas, and the general scientific literature.

Effects on DO will vary spatially in the reservoir in relation to substrate type (*i.e.*, flooded organic materials vs. mineral substrate), effects of erosion of organic shorelines (*i.e.*, peat) on TSS (*i.e.*, suspended organic materials) and substrate composition (*i.e.*, deposition of organic and inorganic materials), location and aerial extent of peat islands, ice cover (duration and spatial extent), depth, velocity, water residence time, and mixing.

Model predictions are discussed separately for the mainstem area of the reservoir and the lentic, isolated areas of the reservoir below. Maps referred to below depict areas of the reservoir where DO concentrations are predicted to fall within defined ranges identified based on Manitoba PAL water quality objectives (MWS 2011). Note that while there are fewer CCME PAL guidelines for DO than for

MWQSOGs, the CCME guidelines (6.5 and 9.5 mg/L) are equivalent to the most stringent Manitoba objectives for the open water and ice-cover seasons (*i.e.*, presence of early or mature life stages of aquatic life). Discussion of DO modelling results provided below represents a summary of the information presented in the PE SV, Section 9.

Year 1 DO Model Results: Mainstem

Model predictions indicate that the mainstem of the Keeyask reservoir will remain well-oxygenated year-round (*i.e.*, in the ice-cover and open water seasons) across depth and under both the base loaded and peaking modes of operation (PE SV, Section 9; Map 2-12 to Map 2-21). The predicted decrease in DO under "typical" and more extreme (*i.e.*, higher temperatures, lower wind speeds) weather conditions in summer is less than 0.5 mg/L in the area immediately upstream of the GS (*i.e.*, "immediately adjacent to the powerhouse") relative to the inflow concentration (Table 2-13). As the lowest DO concentration measured in the open water season along the mainstem of the Nelson River during the Keeyask environmental studies was 7.61 mg/L, DO would remain above the most stringent Manitoba PAL water quality objective and the CCME guideline for mature life stages of aquatic life (6.5 mg/L) under the range of DO conditions measured in the study area.

Similarly, DO is predicted to decline by less than 0.5 mg/L along the mainstem of the reservoir in winter (Table 2-13). As the lowest DO concentration measured along the mainstem of the Nelson River during the Keeyask environmental studies in winter was 11.10 mg/L, DO would remain above the most stringent Manitoba PAL water quality objective and the CCME guideline for protection of early life stages of cold water aquatic life (9.5 mg/L) under the range of DO conditions measured in the study area.

The surface areas of the reservoir that would remain above the most stringent PAL water quality objectives/guidelines (*i.e.*, 6.5 mg/L in summer and 9.5 mg/L in winter) at all depths are approximately 73.7–91.1 km^2 in summer and 61.6–69.0 km^2 in winter in Year 1 of the Project when effects on DO would be greatest (Table 2-14 and Table 2-15, respectively). These areas represent approximately 76–98% (summer) and 66–74% (winter) of the entire reservoir surface area. The spatial extent of this highly oxygenated area of the reservoir would fluctuate depending on wind speed in the open water season and the mode of operation throughout the year.

Year 1 DO Model Results: Flooded Bays

Dissolved oxygen will be most affected in the nearshore, flooded areas of the reservoir, due to the presence of flooded organic materials, introduction of particulate organic materials from erosion and disintegration of peatlands, shallow depths, low velocities, and higher water residence times. In addition, the presence of peat islands may cause or contribute to localized DO depletion in backbays through decay of peat and/or due to reductions in reaeration due to the physical presence of the islands.

Effects will be greatest in winter when ice cover prevents introduction of atmospheric oxygen to the water column and reduces mixing processes (PE SV, Section 9; Map 2-18 to Map 2-21). Effects in the open water season are highly dependent upon wind speed, although the nearshore, lentic areas will typically contain lower concentrations of DO than the mainstem of the reservoir throughout this season due to lower water velocities, longer residence times, reduced mixing, and the presence of flooded peat.

The largest effects on DO would occur at depth. Temperature modelling indicates that the reservoir will not thermally stratify in summer or winter (see the PE SV, Section 9). However, information collected from the north arm of Stephens Lake indicates that stratification may occur in winter in isolated backbays and nearshore areas and that backbays may also exhibit transient stratification under atypically low wind conditions in the open water season. On this basis, it is expected that thermal stratification may occur in some nearshore areas in winter and infrequently during very hot, calm conditions in summer. This occurrence would exacerbate DO depletion at depth but may improve **epilimnetic** DO concentrations during periods of stratification. Dissolved oxygen modelling also indicates that DO gradients across depth are expected in nearshore areas even where thermal stratification is not predicted.

In winter, DO concentrations will vary in the lentic areas of the reservoir according to depth, substrate, mixing, and the presence of ice. Map 2-20 and Map 2-21 illustrate the predicted concentrations of surface and bottom DO concentration ranges, respectively, after three weeks of ice cover in the reservoir under a peaking mode of operation. Predicted surface and bottom DO concentration ranges under a base loaded mode of operation for a two week simulation period are illustrated in Map 2-18 and Map 2-19. In areas where the water residence time exceeds the duration of the model simulations and mixing is limited (*i.e.*, where DO depletion is evident in the model simulations), DO depletion will continue beyond that predicted by the model over the winter period. The boundary of the area potentially affected by severe DO depletion (*i.e.*, becoming hypoxic or anoxic by winter's end) has not been defined by modelling; however, conservatively, it is assumed that all areas showing marked depletion (*i.e.*, less than 9.5 mg/L by the end of the three week simulation) would continue to decline to very low concentrations by winter's end. However, DO depletion may stabilize at relatively higher concentrations in some areas. Under the base loaded mode of operation, this represents an area of the reservoir of approximately 25 km^2, including areas that would be frozen to the bottom (Table 2-15). Areas that were characterized by DO concentrations greater than 9.5 mg/L after three weeks of ice cover (the mainstem of the reservoir) are expected to maintain high DO concentrations throughout the winter.

Including areas of the reservoir that would be frozen across depth under the peaking mode of operation, approximately 32 km^2 of the reservoir are expected to be below the chronic Manitoba DO objective for the protection of cold water aquatic life and the CCME guideline for the protection of early life stages of cold water aquatic life in winter (9.5 mg/L), all of which are located in nearshore, lentic areas (Table 2-15). The remainder of the reservoir (approximately 62 km^2, depending on water level fluctuations) is expected to exceed Manitoba DO objectives and the CCME guidelines throughout the winter. Water level fluctuations are expected to result in a shifting of the boundaries of DO concentrations between the poorly mixed nearshore areas and areas closer to the mainstem of the reservoir where mixing occurs. Therefore, in these transitional areas, DO concentrations are expected to oscillate along with daily and weekly water level fluctuations.

As DO conditions in winter will be relatively stable once equilibrium is reached, the most applicable Manitoba PAL water quality objectives are the chronic objectives (9.5 mg/L for cold water species and 5.5 mg/L for cool water species). However, the 9.5 mg/L DO objective for cold water species in winter is intended to protect intergravel DO concentrations for the early life stages of fish that spawn on gravel substrates (*e.g.*, trout). This objective may not therefore be applicable (*i.e.*, overly conservative) to the nearshore, newly flooded habitat, due to the composition of the flooded substrate (*i.e.*, organics).

Of the remaining Manitoba DO objectives for the ice-cover season, the most stringent is the 30-day objective of 5.5 mg/L for cool water species. Most of the nearshore areas where DO depletion is anticipated in winter are predicted to below 5.5 mg/L by the end of a three-week simulation and it is expected DO will continue to decline thereafter. In addition, DO may continue to decline to concentrations below this objective over the course of the winter in areas where model predictions indicated DO was less than 9.5 mg/L. Overall, nearshore areas are expected to experience DO conditions below the most-stringent, applicable Manitoba objective and the CCME guidelines for cold water aquatic life and areas of hypoxia or anoxia will occur in shallow, isolated areas of the reservoir over winter.

Based on an approximate ice thickness of 1 m, as described in PE SV, Section 4, some areas of the reservoir are expected to be either completely or effectively isolated from the rest of the reservoir in winter. This occurrence would likely exacerbate DO depletion and the isolated areas are likely to become anoxic over winter. These anoxic conditions coupled with the physical isolation of these areas would likely lead to mortalities of fish and invertebrates. Based on depth contours of the reservoir, areas likely to become isolated in winter are located in peat transport zone 9 (northeast bay of the reservoir (Map 2-22; PE SV, Section 4).

In the open water season, DO concentrations are expected to remain above the most stringent Manitoba PAL water quality objective (30-day average of 6.5 mg/L for the protection of cold water aquatic life) and the CCME guideline for mature life stages (6.5 mg/L) under typical wind conditions (*i.e.*, average wind speed of 15 km/hour [h]) through the majority or entirety of the reservoir (Map 2-12 and Map 2-13, Table 2-14).

Conversely, lower DO concentrations are expected in some of the isolated areas of the flooded bays during low wind events in summer (Map 2-14 and Map 2-15). Manitoba water quality objectives for DO incorporate the concepts of duration and frequency in recognition that the tolerance of aquatic life to changing environmental conditions is related to the exposure regime; the applicable objectives for short-term events are the instantaneous minimum objectives of 4 mg/L and 5 mg/L, for cold water and cool water species respectively.

Under periods of low-wind (*i.e.*, less than 6 km/h for a 12-hour period or longer) and higher air temperatures, model predictions indicate DO would decrease below the Manitoba instantaneous minimum objectives of 5 mg/L and 4 mg/L over approximately 14 km^2 and 10 km^2, respectively, under the peaking mode of operation[1]. In general, modelling indicates that DO may decrease notably in some nearshore areas when wind speeds are less than 6 km/h. However, the duration of the low wind events and the wind speeds that occur prior to these low wind events affect the absolute decreases in DO. An analysis of wind conditions over a typical period from May to September indicates that these low wind conditions (*i.e.*, less than 6 km/h for a 12-hour period) typically occur only 3% of the time during that

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[1] Assuming DO concentrations in areas that could not be modelled due to shallow depths (less than 0.1 m) would be less than 4 mg/L.

period (PE SV, Section 9). Therefore, these low wind and associated low DO events would be short-term (typically less than 24 h) and infrequent.

Resuspension of organic particulate matter (*i.e.*, peat) that is deposited on the bottom of nearshore areas by wind or wave action may cause periodic declines in DO. This may increase the BOD in the surface water and lead to episodic decreases in DO following high wind events, in particular. In addition, the DO model was structured on the assumption that **peatland disintegration** would occur uniformly during the open water period. However, should the disintegration occur in a non-uniform fashion, effects to DO due to this pathway may be larger and more sporadic than predicted by the model and episodic decreases in DO would be expected.

In summary, during winter, the area over which the most stringent Manitoba PAL water quality objectives and the CCME PAL guideline (both 9.5 mg/L) would be met in the reservoir is estimated as 62–69 km^2, depending on mode of operation. The greatest effects to DO will occur in winter, where a larger area will be affected, the magnitude of DO depletion will be greatest, and the duration of the effects would be longest. As the ice-cover season is prolonged in the area, these low DO conditions would occur for a number of months. Summer DO concentrations are expected to be above the most stringent Manitoba water quality objective and the CCME PAL guideline (both 6.5 mg/L) under median wind conditions throughout the reservoir. Short-term decreases in DO are expected in the nearshore and transitional areas in summer under infrequent low wind events, with DO concentrations declining to below the Manitoba instantaneous minimum water quality objectives and the CCME PAL guideline in shallow isolated areas of the reservoir.

Ice Regime and DO

Project-related changes in the ice regime could affect DO due to effects on reaeration. The DO model, which included the majority of the reservoir, incorporated the loss of open water at Gull Rapids as complete ice cover was assumed over the modelled area. However, the model did not incorporate potential effects of increased ice cover in the riverine section of the reservoir, as the model did not extend this far upstream. The ice regime analysis indicates that ice cover will always form in the riverine area of the reservoir and may advance further upstream than under existing conditions, although a portion of the reach from Clark Lake to Birthday Rapids will remain open with the Project (PE SV, Section 4). This could decrease the concentration of DO entering the reservoir through the reduction or elimination of reaeration in this area. However, DO is typically at or near saturation across the mainstem of the study area in winter and the DO model results indicate that DO would drop by less than 0.5 mg/L along the mainstem of the modelled reservoir area with the Project. Therefore, it is not expected that changes to the aerial extent of ice cover in the riverine portion would result in notable decreases in DO in the mainstem of the reservoir.

The Project is also expected to result in earlier freeze up and later breakup, thus extending the duration of ice cover, relative to current conditions. Therefore, low DO conditions may persist for a longer period in the Keeyask reservoir.

Peat Islands and DO

DO concentrations may be lower in the vicinity of floating peat islands; low DO concentrations were observed under floating peat in the ELARP studies (Saquet 2003). However, the magnitude of the effect would depend upon the location and aerial extent of the peat islands (*i.e.*, water depths, velocities, mixing). According to the PE SV, Section 7, the greatest amount of floating peat is likely to accumulate in peat transport zones 11 and 12 (areas depicted in Map 2-22) and DO depletion may be greater in these areas if a substantive amount of floating peat accumulates, notably in shallow, nearshore, poorly mixed areas.

Effects of Primary Producers on DO

As primary producers (*i.e.*, phytoplankton and aquatic plants) may affect DO concentrations in aquatic ecosystems (primary producers generate oxygen in daylight and consume oxygen at night), any Project-related changes in primary production could affect DO concentrations in the Keeyask area. Effects may occur as diurnal oscillations and/or due to **senescence** (*i.e.*, decay processes consume oxygen).

Detectable changes in phytoplankton biomass are not expected in the mainstem of the reservoir due to short water residence times (see Section 4.2.4.2). Therefore, phytoplankton are not expected to cause detectable changes in DO in the mainstem of the reservoir. Phytoplankton abundance is also not expected to increase substantively in the lentic areas of the reservoir during the initial years following impoundment due to reduced water clarity and increases in humic matter and DOC (see Section 4.2.4.2). Therefore, effects of phytoplankton on DO in the lentic areas of the reservoir are expected to be negligible during the initial years of operation. However, when effects of shoreline erosion begin to subside and effects to water colour and DOC decline (*i.e.*, after approximately 5–10 years), phytoplankton abundance may increase in the lentic areas as water clarity is increased. Increases in diurnal oxygen swings may be more pronounced in these areas during the transitional period of reservoir evolution (*i.e.*, 5–15 years) and may occur periodically in the long-term during phytoplankton bloom events.

In addition, senescence of aquatic plants in late fall may lead to short-term decreases in DO concentrations. Aquatic plant beds are expected to begin to develop in the new reservoir between 5 and 15 years after impoundment and eventually occupy shallow areas with suitable substrate. Therefore, in the long-term, temporary decreases in DO may occur in aquatic macrophyte beds in late fall during the senescence phase. Diurnal oxygen swings may also occur within plant beds during the growing season.

Duration of Effects

The duration of DO effects over the longer-term relates to the rate of decay of flooded organic materials and the time period over which substantive peatland disintegration, and therefore introduction of suspended organic materials, will occur. DO conditions are expected to be very similar to existing conditions throughout the operation period along the mainstem of the reservoir, as well as in the majority of deep, lentic areas of the reservoir (*i.e.*, at or near saturation). DO modelling results for Year 5 of operation indicate that a larger area of the reservoir will remain above the most stringent PAL water quality objective relative to Year 1 (Table 2-16). However, lower DO concentrations may occur in portions of the flooded bays of the reservoir, notably in shallow areas, for years following initial reservoir creation. In addition, as peatland disintegration continues over time, the reservoir will be expanded and "new" flooded habitat will be created in the immediate nearshore areas. These areas are likely to experience localized DO depletion in the initial years following their creation.

Overall, effects to DO would be greatest in the initial years following impoundment when the **labile** organic materials would decay and when erosion would be greatest. Dissolved oxygen modelling indicates that **sediment oxygen demand** (SOD) of the flooded materials will be the dominant pathway of oxygen consumption in the reservoir. In addition, peatland disintegration will be greatest in Year 1 of operation, declining rapidly thereafter. Effects to DO due to this pathway would therefore be greatest in Year 1 and would decline in conjunction with reductions in loading of organic materials. Decomposition of the flooded peat will be greatest in the initial years following flooding as the most labile forms of carbon are decomposed, with decomposition rates declining over time. Additionally, in areas where mineral sedimentation will occur, effects to DO will decline as the mineral sediments are deposited over organic areas and reduce the overall SOD by acting as a physical cap. As discussed in Section 3.4.2.2, the majority of the lacustrine portion of the reservoir (*i.e.*, area around what is currently Gull Lake) will become sedimentary and by approximately Year 30 of operation, substrate will be primarily mineral in the reservoir. Small, localized areas will contain organic substrate over the long-term and localized depletion of DO may persist in these areas for decades.

The ELARP studies have indicated that the largest fluxes of greenhouse gases (GHGs) from decomposition of flooded peat occur in the first 5–10 years following inundation, representing decomposition of peatland vegetation, with continued decomposition of subsurface peat for approximately 2000 years beyond (Kelly *et al.* 1997; Dyck and Shay 1999). These studies suggest that effects related to flooding (*e.g.*, DO depletion) would begin to decline after approximately 5–10 years over flooded areas. However, localized depletion may occur for longer periods in the vicinity of floating peat islands (Saquet 2003).

Similar temporal trends have been observed in other hydroelectric reservoirs. Key water quality variables, including DO, had "returned to pre-construction values" in Hydro Quebec's Opinaca and Robert-Bourassa reservoirs after approximately 9 or 10 years post-flood and in the Caniapiscau Reservoir return to "natural conditions" was nearly complete after 14 years (Hayeur 2001). Hayeur (2001) suggested that the more lengthy recovery period for the latter reservoir was related to the prolonged period of impoundment (*i.e.*, three years vs. six months for the other reservoirs). Similarly, water quality conditions of the reservoirs of the La Grande Complex returned to natural levels within 10–15 years post-flood.

Information collected from Stephens Lake indicates that low DO conditions continue to occur in areas that thermally stratify in winter (*i.e.*, depletion is observed at depth) and in isolated, nearshore areas with organic substrates in winter as well as under atypically low wind events in summer. The offshore area of the north arm of Stephens Lake is currently relatively well-oxygenated in the open water season, indicating that effects to DO observed in this area following reservoir creation in the initial years following impoundment (*i.e.*, 1972 and 1973) have since been eliminated.

Synthesis: DO

Flooding and peatland disintegration are expected to cause decreases in DO concentrations in the nearshore, lentic areas (*i.e.*, flooded bays) of the reservoir with poor mixing and long residence times in the open water and ice-cover seasons. The effects are expected to be relatively long-term (*i.e.*, 10–15 years) but in highly isolated nearshore areas where organic substrates persist and/or where floating peat islands are present, the duration of effects may be longer (*i.e.*, greater than 30 years). In addition, temporary decreases in DO may occur over the long-term in association with fall senescence of aquatic plant beds and/or periodic phytoplankton bloom events.

The majority of the reservoir is expected to remain well-oxygenated year-round due to high volumes/flows and short water residence times. In summer, DO concentrations are expected to be above the most stringent Manitoba PAL water quality objective and the CCME PAL guideline (6.5 mg/L) under median wind conditions throughout the reservoir. During low wind events, short-term decreases in DO are expected in the nearshore areas in summer and shallow isolated areas will experience DO concentrations below the Manitoba instantaneous minimum water quality objectives and the CCME PAL guideline. These events are expected to be infrequent, based on analysis of wind speeds at Gillam Airport. The area over which the most stringent Manitoba water quality objective (chronic objective of 6.5 mg/L) and CCME guideline (6.5 mg/L) is expected to be met in summer would vary according to the mode of operation (water level fluctuations) and wind speeds, but is expected to include the mainstem of the reservoir, including the area immediately adjacent to the powerhouse (*i.e.*, near the GS) and substantial portions of the flooded bays. Localized depletion of oxygen may occur in areas where substantive areas of peat islands may accumulate, particularly if they occur in shallow, flooded areas.

Greater effects to DO in the Keeyask area will occur in winter, where a larger area will be affected, the magnitude of DO depletion will be greatest, and the duration of the effects would be longest. In winter, the area over which the most stringent Manitoba PAL water quality objectives and the CCME PAL guideline (9.5 mg/L) would be met in the reservoir is estimated as 62–69 km^2 (representing approximately 66–74% of the total reservoir area), depending on mode of operation. Anoxic and hypoxic conditions are expected to develop in nearshore, lentic areas over flooded terrestrial habitat with limited mixing with the mainstem in the ice-cover season. As the ice-cover season is long in the area, these low DO conditions would occur for a number of months.

There are no Manitoba or CCME guidelines for DO for recreation or drinking water quality. However, development of anoxic conditions in the flooded backbay areas could adversely affect the aesthetics of those areas due to production of unfavourable odours.

2.5.2.2.3 Total Dissolved Gases

The concentration of total dissolved gases (TDG) is often increased downstream of hydroelectric developments because air entrained in water as numerous small bubbles (Abernethy *et al.* 2001) plunges into deeper water (*e.g.*, below spillway plunge pools) and the trapped air comes under sufficient pressure to be forced into solution (Arntzen *et al.* 2009). When the water subsequently surfaces downstream, the sum of the partial pressures of all dissolved gases exceeds local atmospheric pressure, a condition known as total dissolved gas super-saturation (TDGS). This primarily physical process can have major biological ramifications because, depending on the degree of TDGS, gas bubbles may develop in the aquatic organisms inhabiting the super-saturated water. In fish, this causes a condition known as gas bubble trauma (GBT) in which the abnormal presence of gases can block respiratory water flow and blood vessels, tear tissues, rupture the swimbladder, and may result in death (Bouck 1980; CCME 1999; updated to 2012). Effects are commonly observed at TDG pressures of 110%, but symptoms may occur at lower concentrations if fish are restricted to shallow (less than 1 m) waters (Fidler and Miller 1997). Conversely, fish can compensate for the increased TGP (total gas pressure) by moving into deeper water (Bouck 1980), which is probably one reason why massive mortalities of wild fish below waterfalls (where TDGS can occur naturally; Fidler and Miller 1997) have not been reported.

TDGS is well documented from locations downstream of hydroelectric dams on the Columbia River in the US (Urban *et al.* 2008; Tanner et al 2010) and British Columbia (Fidler and Miller 1997). Little information on TDGS exists for other locations in Canada, including hydroelectric installations in Manitoba. A recent study on the Nelson River with locations upstream and downstream of Gull Rapids and the Kelsey and Limestone GSs has indicated that presently no substantial (greater than 103%) TDGS downstream of Gull Rapids exists and that TDGS of up to 109% and 118% occur at locations downstream of the Kelsey and Limestone GSs, respectively (Jansen and Cooley 2012). These results are from only one series of measurements taken at only two depths, in a limited area, and at the prevailing flow of the Nelson River and the spill rate at each station. Thus, they present only a snapshot of TDG conditions the two stations and Gull Rapids and do not characterize its full range.

Based on the results of the Jansen and Cooley (2012) study, and the fact that the design of the Keeyask spillway and potential adjustments during its operation will incorporate a number of features aimed at minimizing TDGS (PE SV, Section 9.4.3.), it is expected that TDG pressure downstream of the Keeyask GS will be within or less than the ranges observed at the Kelsey and Limestone GSs. The effects on TDG pressure are also anticipated to be local, long-term and intermittent as TDGS is expected to mainly occur when the spillway is in operation.

No water quality objectives for TDGS exist for Manitoba. The national water quality guidelines for PAL do not provide a single numerical value, however for the conditions downstream of the Keeyask GS (*i.e.*, water depths greater than 1 m) a guideline of approximately 110% TDGS applies (CCME 1999; updated to 2012). Therefore, the operation of the Keeyask GS has the potential to elevate, at least temporarily, TDGS to levels where guideline values are exceeded and that may result in deleterious effects on fish, invertebrates and amphibian larvae. Because of the potential for swimbladder overinflation, fish are generally more sensitive to TDGS than other organisms (CCME 1999; updated to 2012). Because the biological effects of TDGS are modulated by water temperature and depth, fish life stage, and several other environmental variables (CCME 1999; updated to 2012), their extent and magnitude may differ with the specific condition at a location and identical percentages of TDGS can lead to different biological outcomes. No information of the effect of gas super-saturation on the local aquatic fauna is available for any of the existing generating stations on the Nelson River or in Manitoba. Because of the relative high uncertainty in the predictions of TDGS effects on the aquatic biota, field studies designed to detect signs of GBT and other symptoms of TDGS will be part of a post-Project monitoring program.

2.5.2.2.4 pH

pH may be reduced in newly created reservoirs as a result of decomposition of flooded terrestrial vegetation (*e.g.*, Hayeur 2001). This effect appears to have occurred in the north arm of Stephens Lake during the initial years post-flood (see Section 2.4.3.2 and Appendix 2E for additional discussion), but pH had increased to levels similar to the southern portion of the lake and other sites on the mainstem of the Nelson River by the 1980s. All measurements collected in Stephens Lake from 1972 onwards were within Manitoba and CCME water quality guidelines for the protection of aquatic life indicating that, while pH appears to have been reduced post-impoundment, it did not result in conditions unsuitable for aquatic biota. Currently, pH is somewhat lower in backbay areas of Stephens Lake relative to more offshore areas, indicating that localized reductions in pH may persist for a longer time period; however, these lower pH conditions also reflect the effects of local drainages. Studies of Hydro Quebec reservoirs have also reported temporary reductions in pH lasting for approximately 10–15 years, whereafter levels return to near pre-project conditions (*e.g.*, Hayeur 2001). Typically, as for other water quality variables affected by flooding, the greatest effect is observed in the initial years following inundation.

It is expected that pH will decrease in the nearshore, lentic areas of the Keeyask reservoir due to flooding, as is commonly observed in new reservoirs. Humic and **fulvic acids** released from peat contribute to acidity in surrounding drainages (Faithfull *et al.* 2006). *Sphagnum*-dominated peatlands are also characterized by acidic conditions (pH of 3.8–4.2; Svahnback 2007) and flooding of this type of organic materials would conceptually have a greater effect on surface water pH than less acidic types of terrestrial habitat. Peat lakes also generally exhibit lower pH (less than 7.0) than typical lakes (*e.g.*, Faithfull *et al.* 2006) and runoff from natural *Sphagnum*-dominated peatlands and from peat production areas indicate considerably acidic conditions (*e.g.*, reviewed in Svahnback 2007).

pH may also be altered through indirect effects to primary producers. Increased primary production may lead to increases in pH in daylight hours due to the effects of photosynthesis and to decreases at night due to respiration. This effect creates a diurnal swing in pH levels and can either exacerbate effects on pH related to flooding (*i.e.*, overnight) or mitigate these effects (*i.e.*, in daylight). As primary productivity (*i.e.*, algae) is not expected to be notably increased in the lentic areas of the reservoir during the initial years of operation (see Section 4.2.4.2), when the effects of flooding on pH would be greatest, this pathway is not expected to notably alter pH. Phytoplankton may become more abundant in the longer-term, after water clarity increases and following decomposition of the labile carbon in the flooded peat. This may contribute to small diurnal fluctuations in pH but it is expected that pH would still remain within Manitoba and CCME water quality guidelines for the PAL (6.5–9) and recreation (5-9) and the Manitoba and CCME aesthetic objective for drinking water (6.5–8.5).

pH is currently relatively basic (mean of approximately 8.0) in the study area and surface waters in general would be classified as "least sensitive" to acidification on the basis of alkalinity (Saffran and Trew 1996). Therefore, the study area has a good capacity to buffer the effects of acidification pathways including the effects of flooding. This is supported by monitoring data collected in Stephens Lake in the initial years following flooding (see Section 2.4.3.2) where pH was reduced in the north arm but remained within the Manitoba and CCME water quality guideline range for the protection of aquatic life. Additionally, pH measured near the mouths of small tributaries to the lower Nelson River and in backbays in Stephens

Lake, while somewhat lower than the Nelson River, is within the Manitoba and CCME PAL guidelines and typically above 7.0.

Effects on the lotic areas of the reservoir are expected to be small and not detectable due to the large volume of flow and short residence times and pH is expected to remain within Manitoba and CCME PAL, recreational, and aesthetic drinking water quality guidelines. pH measured in the southern portion of Stephens Lake following creation of the reservoir was similar to levels measured upstream and downstream on the Nelson River and there was no indication that pH was notably changed along the main flow area of the lake (see Section 2.4.3.2 and Appendix 2E).

Overall, effects to pH (*i.e.*, a decrease) are anticipated within nearshore areas of the reservoir, notably shallow, lentic areas, that have long residence times, low mixing, and are located over flooded terrestrial habitat. pH is expected to decrease in these areas during the initial years following flooding, but is anticipated to remain within Manitoba and CCME PAL and recreational water quality guidelines and the aesthetic objectives for drinking water quality in most or all areas. No effects on the mainstem are expected.

The duration of effects on pH are expected to be similar to those predicted for DO (*i.e.*, 10–15 years). A reduced pH was observed in the north arm of Stephens Lake in the initial years following flooding, although it increased to levels similar to the mainstem of the Nelson River within approximately 15 years post-flood. Slightly lower pH continues to persist in isolated backbays in the north arm of the lake in areas with poor mixing, local drainage inflows, and organic substrates, and this may also occur in similar areas of the Keeyask reservoir in the long-term. Monitoring in other boreal reservoirs has indicated that water quality conditions, including pH, typically return to pre-flood conditions within approximately 10–15 years (Hayeur 2001).

2.5.2.2.5 Total Suspended Solids/Turbidity

TSS and turbidity may be affected by erosion of mineral or organic shoreline materials in combination with changes in the hydraulic regime that affect sediment transport and deposition. TSS is defined here as organic and inorganic materials that are retained on a standard-sized filter (typically 1.5 micrometre [μm]). Predicted changes in TSS during the Project operation period were generated separately for mineral erosion (*i.e.*, “mineral TSS”) and disintegration of peat (*i.e.*, “organic TSS”) and are presented in the PE SV, Section 7. The following is intended to provide a brief summary and integration of these predictions and describe how these changes may affect water quality and aquatic biota. Mineral TSS predictions were based on the modelling reaches and shallow/deep areas indicated in Map 2-23 and organic TSS predictions were based on peat transport zones as shown in Map 2-22. Peat transport zones 4, 5 and 7–13 (note: there is no zone 6) are composed entirely of lentic habitat, whereas peat transport zones 1–3 contain both lotic and lentic habitat and are deeper (*i.e.*, composed largely of deep habitat; see Section 3.4.2.2). Additionally, peat transport zones 7–13 are composed mostly of flooded habitat (see Section 3.4.2.2).

Predicted effects of the Project on the spatial distribution of mineral and organic TSS are somewhat different. In general, effects of the Project on organic TSS are expected to dominate in the flooded, nearshore areas, whereas Project-related effects on mineral TSS would be greatest in the lotic areas (*i.e.*, mainstem). The following provides a brief overview of these predicted changes. Detailed descriptions of the effects of the Project on organic and mineral TSS are presented in the PE SV, Section 7.

As described in the PE SV, Section 7, mineral TSS is generally predicted to decrease in the shallow and deep areas of the reservoir with the Project, most notably under high flows (95th percentile), although small increases (1–4 mg/L) are projected in some areas under some conditions (*i.e.*, different flows and years of operation). The predicted changes in mineral TSS are also relatively similar for the peaking and base loaded modes of operation for median and high flows. In general, the predicted decreases (or occasionally increases) in mineral TSS are less than 5 mg/L under low, median, and high flows in shallow and deep areas for Years 1 and 5 of operation. The major exception would occur under high flows in reaches 7 and 8 (at the downstream end of present day Gull Lake) and most notably reach 9 (the reservoir immediately upstream of the GS) where larger decreases (up to 14 mg/L below background) are expected.

Mineral TSS would generally remain within the chronic Manitoba PAL water quality objective and the CCME PAL guideline (a change of less than or equal to 5 mg/L relative to background, where background TSS is less than or equal to 25 mg/L). The exceptions would occur in the immediate reservoir (reach 9) and reach 8 (the area north of Caribou Island) under high flow conditions, where decreases may be larger than the Manitoba water quality objective.

As described in the PE SV, Section 7, although mineral TSS will generally decline in nearshore areas with the Project despite the increase in mineral erosion, episodic resuspension of fine particles may occur in the nearshore areas of the reservoir. Therefore, mineral TSS concentrations may increase during high wind events. Similarly, episodic erosion events may lead to episodic increases in TSS in the nearshore environment.

Changes in mineral TSS beyond Year 5 were predicted for the base loaded operation scenario under median flows only. Mineral TSS is predicted to be similar to or lower in Years 15 and 30 relative to earlier years of operation, under median flows in the deeper, lotic areas of reaches 6–9 (*i.e.*, the central areas of the reservoir). An equilibrium is predicted by Year 15. . Although modelling was not conducted for time frames beyond Year 5 for the high flow condition, it is expected that the magnitude of changes in TSS for the long-term period would be similar to those predicted for Year 5 (i.e., up to 7-14 mg/L near the GS). Therefore, the long-term effects on TSS (i.e., decreases) are expected to be within the Manitoba PAL objective more than 50% of the time and the largest decreases predicted under high flow conditions would occur in the areas closest to the GS.

As described in the PE SV, Section 7, effects of the Project on organic TSS are not expected to be detectable along the main flow of the reservoir (*i.e.*, in lotic areas) but would result in detectable increases in the nearshore, lentic areas in Year 1 of operation. In addition, organic TSS concentrations will vary across the lentic areas of the reservoir due to spatial differences regarding peatland disintegration, local bathymetry, and the water regime. For the purposes of quantitatively estimating the effects of this pathway on TSS, it was assumed that organic TSS would be introduced evenly over the open water period and that some accumulation (*i.e.*, TSS carry-over between days) may occur due to longer water residence times in the peat transport zones (*i.e.*, “average conditions”). Modelling predictions presented in the PE SV (Section 7.4.2.3) represent the maximum predicted increases within each peat transport zone. Overall, the largest increases in organic TSS would occur in peat transport zones 7–9, 11, and 12, which are flooded, lentic areas.

Organic TSS is predicted to remain within the Manitoba PAL water quality objective and the CCME PAL guideline (*i.e.*, less than or equal to 5 mg/L change from background) in peat transport zones 1–3 (which includes the main flow of the Nelson River, including the area immediately adjacent to the GS) in Year 1 where flow and mixing are high. In addition, the predicted decreases in mineral TSS in these areas will likely offset any increases in organic TSS.

The upper range of predicted increases are above the Manitoba PAL water quality objective and the CCME PAL guideline in peat transport zones 7–9, 11, and 12 (*i.e.*, maximum predicted increases ranging from 8–21 mg/L). Increases in organic TSS are predicted to remain within the Manitoba PAL objective and the CCME PAL guideline in the remaining areas (peat transport zones 5, 10, and 13).

As peatland disintegration will decrease notably after Year 1, increases in organic TSS will decline rapidly thereafter. The increases in organic TSS in the flooded bay areas would also be somewhat offset by predicted decreases in mineral TSS. However, changes in mineral TSS are expected to be small (less than 5 mg/L) relative to the predicted increases in organic TSS for some of the flooded backbays.

It should be noted that like mineral erosion, peatland disintegration will likely not occur in a uniform manner over the open water season and statistically rare events could occur in which larger quantities of peat and mineral soils are introduced to the water column. In addition, resuspension of settled organic TSS may also occur in the nearshore areas during high wind events. On that basis, it is likely that short-term increases in organic TSS that exceed the short-term Manitoba PAL water quality objective and CCME PAL guideline (increase of 25 mg/L above background) may periodically occur in some nearshore areas.

Overall, effects of the Project on TSS (*i.e.*, inorganic and organic materials collectively) would be dominated by effects to organic TSS in the flooded lentic habitat and effects to mineral TSS in the deeper, lotic areas. Therefore, collectively the information indicates general reductions in TSS along the mainstem, most notably under high flow scenarios, and elevated concentrations of organic TSS in nearshore, lentic areas of flooded bays, most notably in peat transport zones 7–9 and 11 (shallow flooded bays off the mainstem of present-day Gull Lake). Effects on organic TSS would be greatest in Year 1, declining rapidly thereafter. Effects to mineral TSS would be more long-term as the major driver is a reduction in water velocities in the reservoir.

Changes in TSS may affect primary producers (through changes in the characteristics and penetration of light), fish, and invertebrates. Fish and invertebrates may be directly or indirectly affected by changes in TSS. Direct effects to fish and invertebrates are generally considered in terms of increases in TSS and may include behavioural alterations, reduced growth or condition, physiological stress, and in the most severe instances mortality. Indirect effects include changes in the food web (*e.g.*, reductions in primary production due to reduced water clarity, reduced abundance of benthic invertebrates due to increased TSS and/or sedimentation causing reductions in the abundance of fish diet items), which are considered in Section 4. Potential effects of changes in TSS on water clarity are discussed in the "Water Clarity" section below.

Increases in TSS within the order of tens to hundreds of mg/L are generally associated with sub-lethal effects to fish such as behavioural alterations, reduced growth or condition, and physiological stress (*e.g.*, DFO 2000). Acute toxicities are generally reported for concentrations ranging from the hundreds to hundreds of thousands of mg/L (DFO 2000; Robertson *et al.* 2006). Therefore, the predicted maximum increases in organic TSS in the flooded, lentic areas of the reservoir in Year 1 could result in sub-lethal effects to fish, but estimated concentrations are well below **acute toxicity** levels. Sub-lethal effects may include alterations in behaviour, such as feeding and predation, growth, and condition.

Increases in organic TSS are predicted to decrease rapidly after initial full impoundment. As described in the PE SV, Section 7, maximum concentrations of organic TSS in the peat transport zones are predicted to range from less than 1 to 4 mg/L in Year 2 and by less than 1 to 1 mg/L by Year 5. Therefore, it is expected that increases in TSS would remain within the chronic Manitoba PAL water quality objective and CCME PAL guideline (5 mg/L change from background) by Year 2 of operation.

There are few studies that have reported the acute or chronic toxicity of TSS to fish species represented in the Aquatic Environment Study Area. Lawrence and Scherer (1974) reported that the 96-hour lethal concentration (LC50) for lake whitefish (*Coregonus clupeaformis*) was 16,613 mg/L. McKinnon and Hnytka (1988) found relatively high increases in TSS (instantaneous maximum = 3,524 mg/L and 1-day average concentration = 524 mg/L) caused by winter pipeline construction did not have any direct effect (no downstream emigration and no mortalities) on the fish community of Hodgson Creek, NT. This study is notable as four of the fish species found in Hodgson Creek - northern pike (*Esox lucius*), lake chub (*Couesius plumbeus*), longnose sucker (*Catostomus catostomus*), and burbot (*Lota lota*) - are also found in the Aquatic Environment Study Area.

As indicated in Section 5.4.2, northern pike may spawn in the nearshore areas of the Keeyask reservoir, even during the initial years of operation. Therefore, early life history stages of northern pike may be exposed to elevated concentrations of TSS for several years post-impoundment. No information on the acute or chronic toxicity of TSS to northern pike eggs or larvae could be located. Information for early life history stages of other species represented in the Aquatic Environment Study Area is also sparse and many of the available studies do not differentiate between the effects of suspended particulate materials and sediment deposition. However, the available scientific literature indicates a potential for reduced hatching success in salmonids exposed to elevated TSS concentrations on the order of two months or more, at concentrations ranging from 6.6–157 mg/L (Table 2-17). In addition, northern pike eggs would also be exposed to the combined effects of sedimentation and elevated TSS. Therefore, should northern pike spawn in the nearshore, flooded areas of the reservoir in the initial years of operation where organic TSS will be notably elevated, reduced hatching success of northern pike eggs is likely.

Conversely, elevated TSS and turbidity can provide benefits to some fish species and life history stages. Reduced water clarity can reduce the risk of predation by visual predators, which in turn can enhance survival of juvenile fish (*e.g.*, Sweka and Hartman 2003) and may favour planktivorous fish (De Robertis *et al.* 2003). Alternatively, increased TSS and turbidity may be detrimental to visual predators (De Robertis *et* *al.* 2003). Therefore, nearshore areas may favour some fish species and/or life history stages during the initial years of operation when TSS is notably elevated.

The Manitoba and CCME guidelines for drinking water refer to turbidity and not TSS and are intended to be applied to treated water. Both guidelines indicate very low permissible levels (*i.e.*, 0.3/1.0/0.1 NTU) which are currently not met anywhere in untreated surface waters in the study area and effects of the Project will not change the occurrence of these exceedances.

There is no Manitoba recreational guideline for TSS or turbidity. The recreational guideline suggested by Health and Welfare Canada (1992) is 50 NTU and is intended to "satisfy most recreational uses, including boating and swimming" from the perspective of provision of adequate visibility through the water from a safety perspective (*e.g.*, to facilitate visibility of subsurface hazards). While TSS is generally correlated to turbidity, the precise relationship is typically highly site-specific and absolute turbidity measurements are dependent upon the methods used for measurement. Therefore, a quantitative prediction of Project effects on turbidity and subsequent comparison to the suggested Health and Welfare Canada (1992) recreational guideline cannot be readily made. However, it is assumed that turbidity will exceed 50 NTU in nearshore flooded areas that are exposed to peatland disintegration and mineral erosion, at a minimum periodically during Year 1 of operation.

2.5.2.2.6 Organic Carbon

Organic carbon is commonly increased in newly formed reservoirs due to decomposition and leaching of flooded organic materials. For example, Jackson and Hecky (1980) reported that OC was higher in "backwater" areas of Stephens Lake, Notigi Lake, SIL, and the reservoir of the Kelsey GS in the 1970s due to the effects of flooding and increased water residence times. Similarly, Moore *et al.* (2003) reported increases in DOC in an impounded wetland caused by decomposition of plant tissues and peat.

There is some indication that DOC increased in the offshore area of the north arm of Stephens Lake in the initial years post-flood, but concentrations measured in recent years in the offshore area are similar to those measured in the southern area of the lake and other sites on the Nelson River. The increases in the offshore area observed in the 1970s were also relatively small - approximately 1–4 mg/L higher than observed in the southern mainstem area. DOC and TOC continue to be somewhat higher in isolated backbays in Stephens Lake relative to offshore areas, reflecting the inputs of the small tributary drainages in these areas. TOC and DOC are notably higher in large, but particularly in small, tributaries to the lower Nelson River and associated lakes, relative to the mainstem of the Nelson River (Figure 2-9). In addition, DOC and TOC are typically higher in waterbodies with high proportions of peat in their drainage basins and peat lakes generally contain high concentrations of OC in water (*e.g.*, Faithfull *et al.* 2006; Kortelainen 1993).

It is expected that creation of the reservoir will increase TOC and DOC in the water column due to decomposition of flooded organic materials (*i.e.*, peat), increases in organic TSS (*i.e.*, particulate peat), and increased water residence times (see PE SV, Section 4). As discussed in various sections herein, increases in DOC/TOC may also affect the internal cycling and availability of other water quality variables and affect light availability.

Effects of the Project would be greatest in nearshore flooded areas, particularly in environments with long residence times and low mixing. As for other water quality parameters, increased DOC/TOC would be most pronounced during the initial years following creation of the reservoir and would decline thereafter as labile organic matter is decomposed and as the rate of peatland disintegration decreases. Backbay areas that receive local runoff/drainage from surrounding peatlands would be expected to exhibit higher concentrations of DOC and TOC than the mainstem of the reservoir over the long-term, due to the influence of these drainages. Currently, DOC/TOC concentrations are somewhat higher in backbay areas of Stephens Lake relative to the offshore areas.

It is not expected that DOC or TOC would increase notably in the mainstem of the reservoir and increases would likely be undetectable in offshore, lotic habitat. Concentrations of DOC measured in the southern mainstem area of Stephens Lake following creation of the reservoir (1972) were similar to concentrations measured on the Nelson River upstream of the lake. In addition, while TSS concentrations are predicted to decrease along the mainstem of the reservoir, TOC is not currently correlated to TSS along the mainstem of the Nelson River (Figure 2H-40). Therefore, no changes to TOC are anticipated in the main flow of the reservoir.

There are no Manitoba or CCME guidelines for organic carbon for the protection of aquatic life, recreation, or drinking water.

2.5.2.2.7 True Colour

True colour, which increases with the content of humic and fulvic acids, is typically high in peatland drainages and **dystrophic** lakes (*e.g.*, Faithfull *et al.* 2006). Waters in such areas are brown or tea-coloured due to the introduction of humic and fulvic acids from the terrestrial vegetation. DOC and TOC are typically positively correlated to water colour and the concentration of TOC in lakes has been related to the area of peatlands in the surrounding drainage basins (*e.g.*, Kortelainen 1993). TOC and true colour are strongly positively correlated in the north arm of Stephens Lake (Figure 2H-42) and DOC notably increased in the ELARP Lake 979 experimentally flooded peatland (Paterson *et al.* 1997). As the Keeyask reservoir will inundate a substantive quantity of peat and will increase water residence times in flooded bays (see PE SV, Section 4), true colour is expected to increase in these areas, most notably in isolated shallow backbays. As indicated in Section 2.4.2.1, true colour measured in all but one sample collected along the mainstem of the study area (from Split Lake to the estuary) during the Keeyask environmental studies was at or above the Manitoba/CCME aesthetic drinking water quality objective (less than or equal to 15 NTU). Therefore, the Project would be expected to increase the magnitude of exceedances of this aesthetic objective in flooded bays, most notably in shallow, isolated areas.

Effects of flooding on true colour along the mainstem of the reservoir, notably in deep, lotic areas, are expected to be negligible due to the large volume of water and the short water residence times. Conversely, the predicted reductions in TSS along the mainstem of the reservoir may lead to small reductions in colour. However, as true colour and TSS are only weakly correlated along the mainstem of the Nelson River the changes in TSS are not expected to result in detectable changes in this parameter.

There are no Manitoba or CCME guidelines for true colour for the protection of aquatic life or recreation.

2.5.2.2.8 Water Clarity

Water clarity, which can broadly be defined as the depth of light penetration in a waterbody, is a function of dissolved and suspended substances in water. As such, it is commonly described using various direct and indirect measures of light penetration (*e.g.*, Secchi disk depths, light attenuation profiles). TSS (a measure of the suspended solids in water) and turbidity (a composite measure of light scattering in a waterbody that is typically related to TSS) affect light penetration and thus water clarity. In addition, organic matter (measured as DOC/TOC), in particular humic and fulvic acids which impart brown colouration (measured as true colour) to surface waters, may reduce water clarity. All of these parameters are expected to be affected in the Keeyask reservoir through a variety of pathways.

As discussed above, particulate materials (*i.e.*, collectively measured as TSS) are expected to increase in isolated, flooded bays, notably in Year 1, in the reservoir thereby reducing water clarity. Similarly, turbidity, which is correlated to TSS and which will be affected by increases in both suspended and dissolved substances, will increase in these areas.

Lastly, DOC and true colour will increase in the flooded bays as a result of leaching and decomposition of flooded organic materials and suspended organic materials introduced from peatland disintegration and resuspension. Increased concentrations of organic matter and true colour are observed in hydroelectric reservoirs following flooding, downstream of natural peatlands and peat mining areas, and in natural lakes with significant quantities of peat in the drainage basins. Increases in colour (*i.e.*, humic and **fulvic acids**) and DOC in reservoirs and natural lakes has been shown to reduce light penetration as well as the light spectrum (*e.g.*, Hakanson 1995; Gorniak *et al.* 1999, 2002; Faithfull *et al.* 2006).

Effects of flooding and peatland disintegration are not expected to extend into the mainstem of the reservoir (*i.e.*, offshore, lotic habitat). However, alterations in the water regime are predicted to cause reductions in concentrations of TSS along the main flow in the reservoir, which will in turn increase water clarity. This effect would be greatest under high flows when TSS is predicted to decrease by nearly 50% as a result of the Project.

Collectively, water clarity will be reduced in the flooded bays in the reservoir but will be slightly increased along the mainstem of the reservoir. Effects in the flooded bay areas would be greatest in Year 1 and would decline thereafter as peatland disintegration declines and as flooded, labile carbon is decomposed. Increased water clarity along the mainstem would be a long-term effect as it is related to an altered water regime and reservoir morphometry.

Manitoba and CCME guidelines for PAL, drinking water, and recreation relating to TSS and turbidity are discussed in the previous section. Health and Welfare Canada (1992) also recommends a recreational water quality guideline for water clarity based on Secchi disk depth (1.2 m minimum). Secchi disk depths currently exceed this guideline in the study area and the Project will increase the magnitude of exceeding this guideline in backbays where TSS is predicted to be increased, most notably in the initial years of operation. Along the mainstem of the reservoir, water clarity will increase and the recreational water quality guideline may be met in this area as a result of the Project.

2.5.2.2.9 Nutrients

Nutrient concentrations in the Keeyask reservoir may be affected by leaching from, and decomposition of, flooded organic materials, through changes in concentrations of organic and inorganic TSS (which include nutrients) related to erosion and peatland disintegration, changes to sedimentation, and due to changes in the water regime (*e.g.*, increased water residence times in the nearshore areas). The following provides a discussion of the available scientific literature, including information on effects observed in other Manitoba reservoirs, notably Stephens Lake, and a summary of results of a nutrient modelling approach developed to estimate the magnitude of nutrient increases expected due to the Keeyask Project.

Predicted Changes in Nutrients Based on Scientific Literature

Numerous studies have demonstrated a temporary increase in nutrients in reservoirs following impoundment, including reservoirs in Manitoba (*e.g.*, SIL: Hecky *et al.* 1987a; Notigi Lake: Hecky *et al.* 1987a; Stephens Lake: See Section 2.4.3.2 and Appendix 2E). In general, effects of reservoir creation on nutrient concentrations are related to the relative amount of flooded area, the nature of the flooded materials (*e.g.*, organic matter content), reservoir morphometry, and hydrological considerations. Information gathered from Stephens Lake indicates that nutrients, most notably phosphorus, were higher in the northern arm in the initial years post-flood (*i.e.*, 1972 and 1973) relative to the southern mainstem. While pre-Kettle GS water quality data are not available, the relative differences in nutrient concentrations in the north arm versus the southern mainstem in the early years post-impoundment, as well as the observed decrease in nutrients in the north arm over time, suggest the higher concentrations observed in the early 1970s reflect the effects of impoundment. Nutrient concentrations decreased in the north arm within approximately 15 years post-impoundment.

Similar periods for elevated nutrient concentrations in hydroelectric reservoirs have been reported by others (*e.g.*, Hayeur 2001), with recovery to a natural state reportedly occurring approximately 10–15 years post-flood. However, in some cases, concentrations of phosphorus declined below those occurring pre-impoundment and the reservoir became less nutrient-rich than prior to inundation (*e.g.*, Stockner *et al.* 2000). This may occur, for instance, where sedimentation is higher post-impoundment, which results in greater settling of nutrients in the sediments. Without pre-project data for Stephens Lake, it is not known if the current concentrations of TP are lower than they were pre-impoundment. However, that nutrient concentrations are currently lower in the north arm of the lake than in the southern mainstem, coupled with the temporal changes observed in this area and nutrient concentrations observed in a nearby off-system lake (Assean Lake), suggests that nutrients may be lower in the north arm of Stephens Lake than pre-impoundment.

The greatest observed changes in nutrients, and other variables, in newly flooded reservoirs are typically observed over the flooded terrestrial habitat and nutrient gradients are often reported from flooded areas out into the main body of the reservoir. Spatial gradients in water quality conditions of the north arm of Stephens Lake are still observed today and similar gradients were reported in Lake 979 following inundation of a peatland (Paterson *et al.* 1997). The available information for Stephens Lake indicates that nutrient concentrations in the mainstem of the reservoir (*i.e.*, the southern riverine portion) were largely unchanged with creation of the Kettle reservoir, as conditions were similar upstream and downstream of the reservoir 2–3 years post-flood and in the decades to follow.

It is expected that forms of nutrients released from leaching of flooded peat would be dominated by dissolved forms, although introduction and resuspension of settled mineral and organic sediments from erosion and disintegration of shorelines may result in a greater amount of suspended particulate nutrients. DP appears to have notably increased in the north arm of Stephens Lake following inundation (Appendix 2E). Conversely, decomposition of peat would also increase the DOC, and, in particular, humic and fulvic acids, in surface waters and these substances can form complexes with phosphorus, ammonia, and metals. These complexes, in turn, are believed to limit the bioavailability of nutrients to primary producers in some environments, thus attenuating the potential for eutrophication. Paterson *et al.* (1997) suggested that binding of phosphorus by organic complexes may have contributed to low primary production observed in Lake 979 immediately following impoundment of a peatland. DOC additions have even been explored as a mitigation method to reduce the effects of elevated phosphorus on the growth of phytoplankton (Faithfull *et al.* 2006). In general, low productivity in dystrophic lakes (lakes characterized by high concentrations of humic matter, brown water, and low productivity and that are often acidic) is believed to be a result of limited light (due to the coloured nature of the water) and binding of nutrients to DOC.

Chemical processes may release nitrogen and phosphorus at a greater rate if the sediment-water interface is anoxic (*e.g.*, Devito and Dillon 1993; Carignan and Lean 1991). Under anoxic conditions, phosphorus bound to iron oxides and hydroxides in sediments is released and high rates of benthic phosphorus fluxes often occur in wetlands under anoxic conditions (*e.g.*, Faithfull *et al.* 2006; Aldous *et al.* 2005). Conversely, decomposition of organic materials is generally reduced under anoxic conditions – a process that allows for peat to accumulate and for nutrient retention to occur in wetlands (*e.g.*, Duff *et al.* 2009). Lower rates of benthic phosphorus flux have been observed under anaerobic conditions in wetlands (*e.g.*, Fisher and Reddy 2001). As anoxic conditions are expected to occur in shallow, flooded habitat in the Keeyask reservoir in winter, larger benthic nutrient fluxes may occur in these areas over winter.

Literature pertaining to the effects of peat mining on nutrient loading to downstream watercourses similarly indicates that the majority of nitrogen leached from peatlands is the inorganic form (Sallantaus 1983 in Svahnback 2007 indicates that 50–70% of total nitrogen leached from peat production areas is inorganic), with ammonia particularly dominating. The dominant form of inorganic nitrogen that is expected in the surface waters of the Keeyask reservoir is dependent upon the oxygen status; typically, runoff from peatlands or surface waters overlying peat contains more ammonia than nitrate or nitrite when the waters are anoxic and acidic. For example, high ammonia concentrations occur in dystrophic lakes with anoxic and acidic conditions (*e.g.*, Gorniak *et al.* 1999). Additionally, denitrification occurs under anaerobic conditions, which might decrease the nitrate concentrations and overall concentrations of nitrogen. Therefore, ammonia would be expected to dominate over nitrate in anoxic and hypoxic areas (see section on DO for a description of these areas). In winter, where anoxia or hypoxia is predicted to develop during the operation period (see section on DO), ammonia may be the more dominant form of nitrogen present. Although inorganic forms of nitrogen are those used by aquatic plants and algae, organic nitrogen (ON) may be released from flooded soils, as has been observed in some flooded peat areas (Duff *et al.* 2009).

Results of Nutrient Modelling for the Keeyask Reservoir

Estimation of the precise concentrations of nutrients in the Keeyask reservoir immediately post-flood is difficult due to the complexities of, and uncertainties associated with, the pathways that are expected to alter nutrients. However, in consideration of the importance of nutrients in aquatic ecosystems, mass-balance modelling was undertaken to provide an estimate of the potential magnitude of nutrient increases that may occur in the Keeyask reservoir. Two primary pathways considered in detail were:

- Increase in TN and TP in the water column due to increases in suspended organic materials that may arise from peatland disintegration (*i.e.*, "organic TSS pathway"); and
- Increase in TN and TP in the water column due to leaching and decomposition of flooded peat ("flooded peat pathway").

The following provides a summary of the results of this modelling; a detailed description of the methods and results of the modelling exercise is provided in Appendix 2F. Information regarding the effects of the Project on organic TSS is presented in the PE SV, Section 7, and summarized in Section 2.5.2.2.

Collectively, TP and TN are predicted to be measurably increased in the water column in flooded bays, notably shallow, isolated areas, in the Keeyask area as a result of increases in organic TSS (*i.e.*, particulate peat) and due to leaching and decomposition of flooded organic materials (mostly peat and surface litter/vegetation; Table 2-18 and Table 2-19, respectively). Conversely, the combined predicted changes from these two pathways indicate that increases in TP and TN are not expected to be detectable in the main flow areas (*i.e.*, mainstem) of the reservoir where residence times are low and dilution would be high (*i.e.*, peat transport zones 1–3). Predicted increases in TP and TN for the mainstem areas (peat transport zones 1–3) are on the order of 1–2 micrograms per litre (μg/L) and 2–5 μg/L above background, respectively. In addition, TP concentrations may actually slightly decrease along the mainstem of the reservoir due to predicted decreases in TSS, as TP is correlated with TSS.

TN and TP concentrations will be elevated in flooded bays, most notably in the initial years post-impoundment, and concentrations will likely decrease with distance from shore. These effects would be detectable and concentrations may be notably higher than existing conditions in the lower Nelson River and Gull Lake area. Increases of the order of 50–100% for TP could occur, on average, in these areas. TP was approximately 200–300% higher in the offshore area of the north arm of Stephens Lake relative to the southern portion of the lake, as well as upstream and downstream of the lake, in the initial years following creation of the reservoir (1972 and 1973; see Appendix 2E). Conversely, mass-balance modelling indicates higher increases in TN (on the order of 100–200%) in the flooded bay areas of the Keeyask reservoir than was observed in the north arm of Stephens Lake in 1972 and 1973 (concentrations were approximately 11–50% higher than mainstem sites on the river). However, as discussed in Appendix 2E, measurements of nitrogen may have been underestimated in these historical studies.

After Year 1 of operation, peatland disintegration is predicted to drop substantively and organic TSS concentrations would be considerably lower in surface waters. Mass-balance modelling indicates that the increases in TP that would be associated with the organic TSS would not be detectable in Year 5 should this process occur uniformly over the open water season. As nitrogen is more abundant in the peat than phosphorus, increases in TN due to organic TSS in Year 5 may be detectable, but considerably lower than in the initial years of operation.

Effects due to both peatland disintegration (*i.e.*, organic TSS pathway) and flooding would be greatest in Year 1 of impoundment, declining thereafter. The relative influence of the two pathways varies depending on the area of the reservoir due to differences in water volumes, area of flooded peat, and loads of organic TSS that would be introduced from peatland disintegration. Furthermore, as peatland disintegration may be episodic, the relative importance of each pathway would also likely vary over time. In addition, the fraction of TN and TP present in dissolved forms would likely vary spatially and temporally as decomposition of flooded peat would result in the introduction of more bioavailable forms of nutrients and would be more continuous. Effects related to organic TSS are expected to be more episodic and to fluctuate according to the rate and timing of disintegration events as well as to settling rates, wind, and wave action. Higher benthic fluxes of nutrients may also occur in winter where anoxic conditions develop.

Effects of Changes in Mineral TSS on Nutrients

As presented in the PE SV, Section 7, mineral TSS is predicted to decrease with the Project in most areas of the Keeyask reservoir, including the mainstem, lotic area. Predicted decreases in mineral TSS are approximately 2–4 mg/L under 50th percentile flows and 11 mg/L under 95th percentile flows in the immediate reservoir (*i.e.*, offshore, deep area upstream of the GS). TP and TSS are positively correlated while TKN is only weakly correlated to TSS across the study area (Figure 2H-41). In addition, concentrations of TKN are currently very similar along the southern portion of Stephens Lake, despite observed decreases in TSS and TP over this area, indicating that TKN is not measurably affected by sedimentation in Stephens Lake. Therefore, the predicted decreases in TSS along the mainstem of the reservoir will likely result in slightly lower concentrations of TP, but would not likely substantively alter TKN concentrations.

Effects of Floating Peat Islands on Nutrients

In addition, production of floating peat islands due to peat resurfacing also has the potential to affect water quality, particularly in localized areas surrounding the islands themselves. Peatland flooding experiments conducted at the Experimental Lakes Area (ELA) have indicated that the formation of peat islands may increase the temperatures within the peat islands themselves, thus leading to enhanced decay (McKenzie *et al.* 1998). The precise effects of peat islands on local water chemistry and nutrient concentrations will depend upon the locations of the islands (*e.g.*, water depths), the areal extent of the islands, and local conditions such as water residence times and limnology (*e.g.*, occurrence of stratification). However, higher nutrient concentrations may occur in the vicinity of peat islands.

Comparison to MWQSOGs and CCME Guidance for the Management of Phosphorus

Phosphorus is generally regarded as the most limiting nutrient in freshwater ecosystems. TP concentrations are currently above the Manitoba narrative guideline (MWS 2011) in the study area and the Project will result in a greater magnitude of exceedances of this guideline in flooded bays. The CCME

(1999; updated to 2012) has provided guidance for management of phosphorus in freshwater ecosystems. The CCME specifies two triggers for assessing and minimizing risk associated with phosphorus enrichment: (1) the maintenance of a trophic category, defined on the basis of TP concentrations; and (2) an increase less than or equal to 50% above background TP concentrations. Application of the CCME (1999; updated to 2012) trophic categorization scheme to the existing environment indicates that the lower Nelson River and Gull Lake areas are currently "eutrophic" (TP is within the range of 0.035–0.100 mg/L). The first trigger would therefore be to maintain TP concentrations below 0.1 mg/L (the boundary of the next trophic category – "hyper-eutrophic"). Model predictions indicate that on "average" TP will not exceed this trigger in the flooded bays (*i.e.*, peat transport zones 4–5 and 7–13) or along the main flow of the reservoir (*i.e.*, peat transport zones 1–3). However, it is likely that concentrations would exceed 0.1 mg/L in some nearshore areas over flooded terrestrial habitat due to reduced dilution and high residence times and/or during episodic high wind/wave events. These conditions would most likely occur in shallow, isolated areas located over flooded peat and/or during episodic increases in organic TSS.

The second CCME phosphorus management trigger (an increase of more than 50% in TP above background) is likely to be exceeded on average in flooded bays with poor mixing, large amounts of flooding and peatland disintegration, and long residence times. These areas would likely include the lentic peat zones 4–5 and 7–13, but effects would likely be greatest in zones 4, 8, and 11. As TP is not expected to measurably change in the main flow of the reservoir (lotic areas and areas with relatively short water residence times), it is not expected that TP would exceed either CCME trigger in these areas (*i.e.*, peat zones 1–3).

Nutrients: Synthesis of Effects Assessment

Overall, based on the linkages between the Project and water quality, the quantity of peat that would be flooded by the Project, the predicted effects of peatland disintegration, consideration of observed effects in the adjacent Stephens Lake, the wealth of scientific literature on the effects of flooding on nutrients, and the modelling results, it is expected that nutrients (N and P) will increase in isolated, flooded areas of the reservoir. It is further expected that the effects, like other effects to water quality, would be greatest in shallow, flooded habitat with long residence times and would exhibit a gradient of decreasing concentrations from shore out into the mainstem of the reservoir. It is also expected that phosphorus and ammonia may be higher in anoxic areas of the reservoir in winter. In addition, localized increases in nutrients may occur in the vicinity of floating peat islands. The increases in nutrient concentrations are expected to be moderate to large and increases in TP are likely to exceed one or both of the CCME phosphorus management triggers, in the nearshore, isolated, flooded bays.

Effects of flooding and peatland disintegration on nutrients in the mainstem of the reservoir are expected to be negligible due to the large volume of flow and short residence times; small reductions in TP may occur in association with reductions in concentrations of mineral TSS. This is further substantiated by the available information for Stephens Lake which indicates that nutrient concentrations in the mainstem of the reservoir (*i.e.*, the southern riverine portion) were likely largely unchanged with creation of the Kettle reservoir, as conditions were similar upstream and downstream of the reservoir 2–3 years post-flood and in the decades to follow.

While the modelling exercise was based on concentrations of TP and TN in peat (and therefore may be somewhat conservative), it is anticipated that decomposition of flooded organic materials will result in the introduction of dissolved nutrients, which are generally more bioavailable. Increases in DP were notable in the northern arm of Stephens Lake after inundation (Section 2.4.3.2 and Appendix 2E) and benthic fluxes of phosphorus from lake and reservoir sediments and peat are generally in dissolved inorganic forms. Therefore, this pathway is important from a biological perspective as it may result in increases in nutrients in forms that are readily available to primary producers.

However, numerous studies have demonstrated that nutrients are bound by OC — notably humic and fulvic acids — thus reducing the bioavailability to aquatic plants and algae (*e.g.*, Faithfull *et al.* 2006; Jones *et al.* 1988). Therefore, dystrophic (*i.e.*, peat-influenced lakes) lakes frequently exhibit lower levels of primary productivity (or trophic status) than would be predicted on the basis of nutrient concentrations (Faithfull *et al.* 2006). As indicated above, Paterson *et al.* (1997) suggested that binding of phosphorus by organic complexes may have contributed to low primary production in Lake 979 immediately following impoundment. Therefore, the effects of increases in nutrients on primary production may be somewhat mitigated in the Keeyask reservoir due to concomitant increases in DOC.

It is difficult to predict precise estimates of concentrations of ammonia and nitrate associated with flooding. However, it is expected that both parameters will increase in the flooded backbays. Concentrations of nitrate ranged from less than 0.005 to 0.118 mg N/L and averaged 0.036 mg N/L at sites from Clark Lake to Stephens Lake in 2001-2004. Nitrate is therefore on average two orders of magnitude lower than the MWQSOG and CCME PAL guideline (2.93 mg N/L) and it is not expected that the Project would result in exceedances of these guidelines in most or all areas of the flooded terrestrial habitat. The drinking water quality guideline is higher (10 mg N/L) than the PAL guideline and is not expected to be exceeded in the reservoir. Similarly, concentrations of ammonia ranged from less than 0.002 to 0.040 mg N/L and averaged 0.010 mg N/L at sites from Clark Lake to Stephens Lake in 2001–2004. Like nitrate, it is not expected that ammonia would exceed the CCME and MWQSOG PAL objectives/guidelines in particular given the anticipated decrease in pH in these areas, as the toxicity of ammonia decreases and the PAL guidelines increase with decreasing pH.

Based on decades or research pertaining to reservoirs and nutrients, it is anticipated that increases in nutrients would be most pronounced in the first several years post-flood, decreasing thereafter, and likely stabilizing in approximately 10–15 years. Reductions in nutrients over time would occur in accordance with decomposition of organic materials — with labile forms decomposing rapidly followed by slow decomposition of refractory materials — as well as the projected reductions in disintegration of peat over time. In addition, overall retention of nutrients may increase over time once aquatic plants are established in the nearshore areas and nutrients become buried in accumulated detritus (Duff *et al.* 2009).

2.5.2.2.10 Conductivity/Total Dissolved Solids

Similar to other water quality parameters, conductivity and TDS are expected to increase in the nearshore areas over flooded habitat in the Keeyask reservoir, but would remain similar to existing conditions along the mainstem of the reservoir. Effects would arise from decomposition/leaching of flooded organic materials as well as due to disintegration of peatlands in conjunction with increased water residence times. Like other water quality effects, these increases would be greatest in Year 1 and would decrease thereafter as peatland disintegration declines and the labile carbon fraction of flooded peat is decomposed. In addition, conductivity/TDS may be somewhat higher at depth during periods of stratification. There are no Manitoba or CCME guidelines for PAL or recreation for conductivity or TDS. Currently, TDS averages less than 200 mg/L and it is not expected that TDS will increase to concentrations that would exceed the Manitoba or CCME aesthetic drinking water quality objective of 500 mg/L in most or all areas of the reservoir. To be conservative, it has been assumed the aesthetic objective may be exceeded in at least some areas of the isolated backbays over flooded terrestrial habitat during the initial years of operation.

2.5.2.2.11 Metals

The effects of the Projection operation on metals were assessed through consideration of the scientific literature and mass-balance modelling.

Predicted Changes in Metals Based on Scientific Literature

Concentrations of metals in the Keeyask reservoir may be affected by decomposition of and leaching from flooded organic materials, introduction of particulate matter from erosion of mineral solids and decomposition of organic soils, changes in limnological conditions that may affect cycling of metals (*e.g.*, DO concentrations, pH), water residence times, and alterations to sediment transport and deposition.

Of the various metals and metalloids, mercury is of particular concern with respect to hydroelectric development. Flooding of terrestrial organic matter typically results in increased **methylation** of inorganic mercury (*e.g.*, Hall *et al.* 2005) and, as discussed in Section 7, ultimately leads to trophic biomagnification in aquatic food webs. An assessment of bioaccumulation/biomagnification of mercury in fish related to the Project is described in Section 7.2.4.2. Effects of Project operation on mercury in sediments is provided in Section 2.6.4.2.

With respect to water quality, the substantive effect of flooding on mercury in water is a change in the form of mercury (*i.e.*, increases in the fraction of methylmercury), rather than changes in total mercury concentrations. Total mercury concentrations are not greatly increased in surface waters following reservoir creation (*e.g.*, Kelly *et al.* 1997; EC and DFO 1992; Hall *et al.* 2005) and large increases are not anticipated in the Keeyask reservoir on the basis of the available literature. Ramsey (1991b) and EC and DFO (1992) reported that concentrations of mercury in water were not higher in reservoirs along the CRD route following diversion, relative to an upstream lake (Granville Lake). In addition, the mean concentration of mercury measured in surface peat from the study area is similar to concentrations of mercury measured in 1981–82 in unflooded peat adjacent to lakes along the CRD and in flooded peat in lakes along the CRD (Bodaly *et al.* 1987).

Conversely, flooding generally results in a greater relative and absolute concentration of methylmercury in aquatic ecosystems, although the concentrations generally remain relatively low in the water column (*e.g.*, Kelly *et al.*, 1997). For example, concentrations of methylmercury were higher in CRD reservoirs in 1981–1982 than in Granville Lake (EC and DFO 1992). Ramsey (1991b) further reported that concentrations of methylmercury were notably higher over flooded areas.

Methylation of mercury in flooded soils depends on various factors, but is typically highest under anoxic, acidic conditions. Methylmercury production is also related to the quantity and nature of flooded organic matter, generally increasing with increasing OC. However, the quantity of **labile** versus **recalcitrant** organic matter also affects methylation rates. For example, Hall *et al.* (2005) reported similar rates of methylmercury production in flooded upland forests (FLUDEX studies) with lower quantities of carbon than the peatlands flooded in the ELARP studies. It was postulated that this was related to the more recalcitrant nature of peat organic matter. Therefore, while the overall quantity of OC may be higher in peatlands, degradation and methylmercury production rates may be reduced relative to other soils. That is, the total amount of readily degradable OC appears to be the most pertinent factor determining rates of overall degradation and methylmercury production in freshwater systems. Methylmercury production rates from experimental wetland and upland reservoirs at the ELA, ON began to decrease over the first three years of flooding (Hall *et al.* 2005).

There is some indication that sediment resuspension and erosion in hydroelectric reservoirs may enhance the trophic transfer of mercury in aquatic ecosystems by enhancing the bioavailability of mercury to detritus-feeders (Hecky *et al.* 1987b; Mucci *et al.* 1995). Conversely, despite a relatively high concentration of mercury in particulate peat materials released from a peat mine that had settled on a stream bottom, Surette *et al.* (2002) did not observe higher concentrations of mercury in feral fish or transplanted blue mussels in an area impacted by a commercial peat moss operation, relative to a reference site. Surette *et al.* (2002) also reported that concentrations of dissolved mercury were low indicating that introduction of suspended peat materials did not result in a notable increase in the dissolved fraction of mercury. Similarly, Mucci *et al.* (1995) have shown that dissolved mercury may actually decrease due to peatland erosion and/or resuspension of organic particulates due to scavenging by the suspended particulate materials.

Decreases in pH that may occur in flooded bays would also favour the release of metals from the sediments. The capacity of peat to sorb metals (and other substances) is dependent on pH, generally decreasing with increasing acidity (*e.g.*, Couillard 1994; Ringqvist and Oborn 2002). Generally, the pH of *Sphagnum* peat and *Carex* peat is between 4 and 5 and 5 and 6, respectively (Ringqvist and Oborn 2002), and the **chelating** capacity of peat decreases below a pH of approximately 3 (Couillard 1994). Areas of the Keeyask reservoir that would become anoxic in winter may also exhibit higher concentrations of manganese and iron in surface water, relative to the open water season, as these metals are released from sediments under anoxic conditions. Lastly, there is some indication that the adsorptive capacity of peat is reduced by drying (reviewed in Couillard 1994). Therefore, the area of peat that would be subjected to periodic drying due to fluctuating water levels under the peaking mode of operation may release a greater quantity of metals and/or at a greater rate than areas that are permanently flooded.

Results of Modelling for the Keeyask Reservoir and Assessment of Effects to Aquatic Life: Metals

Mass-balance modelling was used to estimate the potential magnitude of increases in metals due to peatland erosion and disintegration and flooding. The intent of this exercise was to determine if these pathways would likely lead to exceedances of water quality guidelines for the protection of aquatic life and drinking water. There are currently no Manitoba or CCME recreational guidelines for metals. The methods and approach taken were consistent with those applied for nutrients, with the exception that ratios of carbon: metals in peat were applied in this instance. A detailed description of the methods and results of this modelling is presented in Appendix 2F. The following provides an overview of the mass-balance model results for the organic TSS and flooded peat pathways of effect collectively.

Considering the results of the mass-balance models collectively, the following predictions can be made regarding changes in metal concentrations in surface waters in the Keeyask reservoir (Table 2-20 and Table 2-21):

- Increases in most metals are predicted to be less than 5% above background and are therefore not expected to be detectable along the main flow of the reservoir (zones 1–3);
- Results of a sampling program conducted in the Keeyask area in 2011 indicate total mercury is below analytical detection limits. The Project could potentially cause increases in mercury that result in exceedances of this analytical detection limit (i.e., 0.000001 mg/L) along the main flow of the reservoir. However, modelling indicates total mercury is not expected to increase above the Manitoba or CCME PAL guideline of 0.000026 mg/L;
- Increases in many metals (antimony, arsenic, beryllium, bismuth, chromium, copper, molybdenum, nickel, selenium, silver, sodium, tin, vanadium, and zinc) are not expected to be detectable in many or all of the more isolated peat transport zones;
- The largest increases in metals due to flooding are expected in zones 4, 8, and 9 where the ratios of flooded peat: water volume are highest. Conversely, effects related to peatland disintegration/erosion are expected to be greatest in zones 7, 8 and 11 (note zone 4 not modelled for this pathway). Considered collectively, the largest increases in metals are predicted to occur in zones 4, 8, and 11 (in decreasing order);
- Most metals (arsenic, chromium, lead, mercury[1], molybdenum, nickel, and uranium) currently meet Manitoba and CCME water quality objectives and guidelines for the protection of aquatic life in the Keeyask area and the combined effects of organic TSS and flooding are not expected to result in exceedances of these guidelines for these substances based on mass-balance modelling;
- Concentrations of aluminum and iron are currently well above Manitoba and CCME water quality guidelines for the protection of aquatic life and the Project will increase the magnitude of these exceedances;
- Similarly, selenium and silver occasionally occur at concentrations at or near Manitoba and CCME PAL guidelines – although the laboratory analytical DLs are at the guidelines. The Project may cause or contribute to exceedances for these parameters. However, the estimated increases in both metals

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[1] Background total mercury concentrations used for the modeling analysis were defined as the mean concentration (0.00000088 mg/L) reported by Kirk and St. Louis (2009) and the mean concentration measured in the study area in fall 2011 (*i.e.*, mean was less than 0.000001 mg/L) in order to facilitate comparisons to the revised Manitoba PAL guidelines for mercury (MWS 2011).

are expected to result in concentrations very near the analytical DL and the effects of the Project on these metals is not likely to be detectable;

- Cadmium, copper, and zinc measured in the Keeyask area were occasionally above the CCME PAL guidelines (which are lower than MWQSOGs) and flooding and/or increases in organic TSS may cause or contribute to exceedances of CCME guidelines for these metals. It is predicted that the Project operation will not result in exceedances of the MWQSOGs for PAL for cadmium, copper, and zinc; and
- Effects of both pathways will decrease over time. Peatland disintegration is expected to decrease substantively after Year 1 (PE SV, Section 7) of operation and effects of flooding typically decline over time as labile carbon is decomposed.

The most substantive Project effect on total metals relates to increases in aluminum and iron, which are currently well above Manitoba and CCME PAL water quality guidelines along the Nelson River system. Although peatland disintegration will contribute to the magnitude of exceedances of Manitoba/CCME PAL water quality guidelines for total iron and aluminum, these increases are likely to be largely in forms with low bioavailability (*i.e.*, in particulate forms). Dissolved forms of iron and aluminum currently comprise small fractions of the total metal concentrations (see Section 2.4.2.1). However, metals may be solubilized from the suspended and flooded peat and could contribute to increases in dissolved metals.

Although leaching and decomposition of flooded peat may increase the concentrations of the dissolved fractions of metals, including aluminum and iron, both metals are known to form complexes with DOC which is also expected to increase due to the Project. Humic and fulvic acids may reduce the bioavailability of metals to aquatic life through formation of metal-DOC complexes (*e.g.*, Gorniak *et al.* 1999). Lappivaara *et al.* (1999) reported that dissolved iron concentrations usually correlate with the concentration of dissolved organic matter and that dissolved humic acids have a strong tendency to bind with ferrous iron. Guildford et al (1987) demonstrated that binding of iron by DOC reduced phytoplankton growth rates in SIL following creation of the CRD. Similarly, Jackson and Hecky (1980) reported that primary productivity was strongly inversely correlated to organic matter (as organic carbon) and iron in Stephens Lake, Notigi Lake, SIL, and the reservoir of the Kelsey GS in the 1970s. They postulated that binding of iron by humic acids reduced primary production.

In addition, a number of studies have demonstrated that the bioaccumulation and/or toxicity of iron and aluminum to fish are lower in humic-rich water. For example, Vuorinen *et al.* (1998) reported that the toxicity of both metals to Arctic grayling (*Thymallus thymallus*) was negatively correlated with dissolved humic materials. Pueranen *et al.* (2003) reported similar results for Arctic grayling and Roy and Campbell (1997) reported similar effects for Atlantic salmon (*Salmo salar*) exposed to aluminum. Lappivaara *et al.* (1999) reported that the bioaccumulation and toxicity of iron in European whitefish (*Coregonus lavaretus*) was negligible in chronic laboratory exposures using naturally iron-rich humic water (*i.e.*, "peat water"). Therefore, the effects of increases in iron and aluminum in the nearshore areas of the Keeyask reservoir may be attenuated by the concomitant increases in DOC.

Furthermore, peat has been employed as an absorbent to remove heavy metals, nutrients, and TSS from various forms of wastewaters and landfill leachates (*e.g.*, Couillard 1994; Akinbiyi 2000) and wastewater treatment system designs, including "flooding" (Couillard 1994). Peat, notably the humic acid component, has a particular ability to absorb cations and has been shown to significantly reduce concentrations of a variety of metals in solution (*e.g.*, Couillard 1994; Ringqvist and Oborn 2002; Kalmykova *et al.* 2008). Collectively, increases in metals in the Keeyask reservoir would be expected to be largely restricted to forms with low bioavailability and/or toxicity to biota.

The presence of aquatic biota in this and other systems with similarly high concentrations of iron and aluminum indicates that the guidelines are likely overly protective for this environment. Lappivaara and Marttinen (2005) report that fresh water in the northern hemisphere "regularly contains several milligrams of iron per liter". The maximum estimated concentration of iron in the reservoir (1.94 mg/L) due to the combined effects of organic TSS and flooding under mean and maximum background iron concentrations is within the range measured upstream at the mouth of the Burntwood River (0.93–2.03 mg/L) during the Keeyask environmental studies and within the range measured in the Burntwood River at Thompson (0.84–2.25 mg/L) from 1997–2006 by Manitoba Water Stewardship (MWS 2006); this reflects the higher concentrations of iron in the Burntwood River relative to the upper Nelson River prior to mixing in Split Lake. Furthermore, predicted concentrations of iron in the nearshore areas are lower than the mean, and well below the maximum, concentrations measured in the Red and Assiniboine rivers over the period of 1997–2006 (Table 2-10). Therefore, even if iron was released from sediments during anoxic periods, such as those predicted to occur in isolated bays over winter, resulting in higher concentrations than predicted using the mass-balance model, concentrations should remain within the ranges observed in other rivers in Manitoba.

Similarly, the maximum estimated concentration of aluminum under mean background conditions (1.88 mg/L) is within the range measured in the Burntwood River at its mouth. Although the maximum estimated concentration of aluminum (2.92 mg/L) is slightly above the range measured in the Burntwood River (1.28–2.74 mg/L) during the Keeyask environmental studies, it is within the range measured in the Burntwood River at Thompson (0.69–3.12 mg/L) from 1997–2006 by MCWS (MWS 2006). The maximum aluminum concentration is also similar to, although slightly above, the mean concentrations measured in the Red and Assiniboine rivers from 1997–2006, but well below the maximum concentrations measured in these southern rivers (Table 2-10). Therefore, total aluminum concentrations should remain well within the ranges observed in other Manitoba rivers, including those with diverse fish species assemblages.

Effects of the Project on methylmercury in surface water are inherently difficult to quantitatively predict. However, as it is well established that reservoir creation/flooding of terrestrial habitat typically results in increased methylation of mercury and an increase in the absolute and relative concentration of methylmercury, the Project is predicted to result in detectable increases in methylmercury in flooded backbay areas. Baseline water quality information indicates that methylmercury is currently below analytical detection limits (0.00000005 mg/L) which are two orders of magnitude below the Manitoba and CCME PAL guideline (0.000004 mg/L). On this basis, increases in methylmercury in surface waters may remain within the MWQSOG/CCME PAL guidelines. However, due to uncertainties respecting these predictions, it is conservatively assumed that methylmercury may exceed the PAL guideline in isolated, flooded habitats during the initial years of Project operation.

Results of Modelling for the Keeyask Reservoir and Assessment of Effects to Drinking Water: Metals

The following predictions can be made regarding changes in metal concentrations in surface waters in the Keeyask reservoir and effects on drinking water quality (Table 2-20 and Table 2-21). Drinking water quality guidelines are intended to be applied to treated drinking water. However, comparison of predicted metal concentrations to MWQSOGs for drinking water to raw water (*i.e.*, surface waters) to provide a conservative assessment of potential effects to drinking water. This comparison indicates the following:

- Most metals currently meet drinking water quality guidelines in the Keeyask area (including antimony, arsenic, barium, cadmium, chromium, copper, lead, manganese, mercury, selenium, sodium, uranium, and zinc) and the combined effects of organic TSS and flooding are not expected to result in exceedances of these guidelines for these substances;
- Concentrations of iron are currently well above the Manitoba/CCME aesthetic drinking water quality guideline and the Project will increase the magnitude of these exceedances;
- The largest increases in metals due to flooding are expected in zones 4, 8, and 9 where the ratios of flooded peat: water volume are highest. Conversely, effects related to peatland disintegration/erosion are expected to be greatest in zones 7, 8 and 11 (note zone 4 not modelled for this pathway). Considered collectively, the largest increases in metals are predicted to occur in zones 4, 8, and 11 (in decreasing order); and
- Effects of both pathways will decrease over time. Peatland disintegration is expected to decrease substantively after Year 1 of operation and effects of flooding typically decline over time as labile carbon is decomposed.

Effects of Changes in Mineral TSS on Metals

As discussed previously, mineral TSS is predicted to be affected by the Project, although to a lesser degree than organic TSS (PE SV, Section 7). The major anticipated change in mineral TSS is a reduction, most notably in the area of the reservoir nearest the GS (PE SV, Section 7). Therefore, in general, this pathway is expected to result in reductions in total metals, most notably those that are positively correlated to TSS (iron, aluminum, barium, chromium, cobalt, manganese, potassium, vanadium, and titanium), in the immediate reservoir. As the effects of flooding and peatland disintegration are not expected to be measurable in the main flow of the reservoir, total metals may decrease near the GS as a result of reductions in mineral TSS.

Metals Synthesis of Effects Assessment

Metals may be either increased (due to flooding and peatland disintegration) or decreased (due to increased sedimentation) during the Project operation period. Total metals will likely increase in flooded bays, largely due to increases in organic TSS and from leaching and decomposition of flooded terrestrial habitat. Most metals are expected to remain within MWQSOGs and CCME guidelines for the protection of aquatic life; however, flooding and peatland disintegration may cause or contribute to exceedances of

MWQSOGs/CCME guidelines for the protection of aquatic life for iron and aluminum (which are currently well above guidelines) and selenium and silver (which occasionally exceed guidelines). The Project may also contribute to exceedances of CCME PAL guidelines for cadmium, copper, and zinc but is not expected to cause increases in these metals above MWQSOGs for the protection of aquatic life. While the Project may cause detectable increases in total mercury and methylmercury, notably in flooded, isolated backbays, it is expected that concentrations of inorganic mercury and methylmercury in surface water will remain within Manitoba and CCME PAL guidelines in most areas; exceedances of the PAL guidelines for methylmercury may occur in highly isolated areas, notably during the initial years of operation. To be conservative, it is also assumed that total mercury may marginally exceed the PAL guideline in isolated backbay areas during the initial years of operation. Based on modelling results and literature regarding measured concentrations of mercury in Manitoba and Ontario reservoirs, it is expected that total mercury concentrations would not exceed 0.00005 mg/L; this value was therefore used as a conservative value to input into the human health risk assessment (SE SV Appendix 5C). Small decreases in total metals are expected in the immediate reservoir, most notably under high flows, due to enhanced sedimentation of mineral TSS.

The Project is expected to increase the magnitude of exceedances of the aesthetic drinking water quality guideline for iron but is not expected to result in exceedances of other MWQSOGs or CCME guidelines for drinking water.

Like other water quality variables, the largest effects to metals are expected in the nearshore areas of flooded bays, most notably in shallow, isolated areas located over flooded peat. Total metal concentrations will increase in these areas due to leaching and decomposition of flooded organic materials and from introduction of eroded mineral and organic materials that will be in suspension.

Dissolved metals may also increase in flooded bays, but concomitant increases in DOC (and notably humic and fulvic acids) are expected to minimize the bioavailability of metals in general to aquatic biota through formation of metal-DOC complexes.

Effects of flooding and peatland disintegration are not expected to cause a detectable increase in metals in the mainstem of the reservoir. However, decreases in mineral TSS in this area may result in decreased concentrations of total metals relative to 'background' conditions (*i.e.*, conditions without the Project). Metals that are positively correlated to mineral TSS (iron, aluminum, barium, chromium, cobalt, manganese, potassium, titanium, and vanadium) would likely be most notably affected.

The duration of increases in metals in flooded bays is expected to be similar to that predicted for other water quality variables. That is, effects would persist for approximately 10–15 years and would be greatest during the initial years post-flood. In particular, effects related to increases in organic TSS would be greatest in Year 1 and would decrease relatively rapidly thereafter as the rate of peatland disintegration decreases. Areas most affected would be expected to be similar to those most affected by DO depletion (*i.e.*, shallow, low velocity, poorly mixed areas over flooded peat) and those receiving the greatest loads of eroded and disintegrated peat. Effects of the Project on the mainstem would be long-term.

2.5.2.3 Stephens Lake Area

With the exception of water treatment plant backwash and treated sewage effluents, potential effects of the Project on water quality in Stephens Lake, downstream of the GS, relate to changes in upstream water quality (*i.e.*, at the GS) and/or changes in physical environment processes downstream of the GS.

Water treatment plant backwash water and treated sewage effluent will be discharged downstream of the powerhouse in the main channel of the Nelson River during Project operation. These effluents will be treated to meet applicable provincial and federal effluent licences, authorizations, and permits (Keeyask GS EnvPP). Although highly localized effects on water quality, including increases in TSS and nutrients, may occur in the immediate vicinity of the outfall, due to the high discharge of the receiving environment, the effects of backwash wastewater and treated sewage effluent on water quality of the receiving environment are expected to be negligible and these effects pathways are not discussed further.

As described in the PE SV, Section 6, shoreline erosion is predicted to be unaffected in the open water season and decreased in the ice-cover season downstream of the GS. Therefore, no change in TSS is anticipated in the open water season, but TSS may decrease in winter as a result of a decrease in erosion processes in this area.

In addition, as described Section 2.5.2.2, water quality effects in the Keeyask area are expected to be largely restricted to nearshore, poorly mixed areas of the reservoir. Consequently, downstream effects on water quality are not expected to be noteworthy as the water quality of the reservoir outflow will not be substantively different than current conditions. The major exception is a predicted decrease in TSS at the outflow of the GS (PE SV, Section 7). The following provides an overview of predicted effects on water quality in Stephens Lake due to Project operation.

2.5.2.3.1 Water Temperature

Water temperature is expected to remain similar to existing conditions at the outflow of the GS; temperatures at the outflow are expected to continue to be very similar to water temperatures at the inflow to the reservoir (see the PE SV, Section 9). However, as described in the PE SV, Section 4, water temperature is expected to be slightly elevated for approximately 800 m downstream of the GS due to the effects of turbine rotors resulting in the creation of an open water area in winter.

2.5.2.3.2 Dissolved Oxygen

As described for the Keeyask area, effects to DO are expected to be small in the main flow of the reservoir and DO is expected to remain at or near saturation at the GS in the open water and ice-cover seasons (PE SV, Section 9). In addition, estimated concentrations of BOD that would arise from peatland disintegration are expected to less than 1 mg/L (PE SV, Section 9), which represents a concentration below the limits of analytical detection, at the outflow of the GS. Therefore, DO conditions in Stephens Lake would not be affected by upstream changes in DO conditions in the reservoir.

The tailrace of the GS will remain open throughout winter to a distance of approximately 800 m downstream of the Powerhouse (PE SV, Section 4). As this area is currently fully ice-covered in winter, the Project will provide additional opportunity for reaeration of surface waters in winter downstream of the GS. Therefore, small reductions in DO that may occur upstream (*i.e.*, less than 0.5 mg/L decreases) should be mitigated downstream of the GS. Collectively, DO is expected to remain similar to current conditions in Stephens Lake and above PAL water quality objectives and guidelines. Changes in phytoplankton in Stephens Lake are not expected to be detectable (see Section 4.2.4.2) and thereby are not expected to cause measurable changes in DO concentrations in this area. As for other water quality variables, no effects to DO are expected for the north arm of Stephens Lake or in the vicinity of the Gillam drinking water intake.

2.5.2.3.3 pH

As no changes in pH are anticipated along the main flow of the reservoir upstream, pH would not be affected in Stephens Lake due to upstream water quality changes. As there will be no flooding downstream of the GS, pH should be unaffected in Stephens Lake. No effects to pH are expected in Stephens Lake, including the vicinity of the Gillam drinking water intake.

2.5.2.3.4 Total Suspended Solids/Turbidity

As described in the PE SV, Section 7, and summarized above, TSS is expected to be lower at the GS during the operation period, relative to conditions that would be expected without the Project (*i.e.*, “background” condition). The largest decrease relative to background (11 mg/L) would occur during high flow conditions (*i.e.*, 95th percentile flows), although TSS is also expected to be lower under median and low flows with the Project.

Currently, TSS concentrations decrease from the inflow to Stephens Lake to the Kettle GS (Figure 2-7; PE SV, Section 7). The Project will result in lower TSS concentrations at the inflow to Stephens Lake (downstream of the Keeyask GS) and decreased concentrations, relative to conditions without the Project, are expected to persist along the mainstem in Stephens Lake for approximately 10–12 km from the GS (PE SV, Section 7). At this point, TSS concentrations are expected to be similar to those that would occur without the Project. Predicted reductions in shoreline erosion in winter in Stephens Lake (PE SV, Section 6), may lead to decreases in TSS during the ice-cover season. No effects are expected for the north arm of Stephens Lake or in the vicinity of the Gillam drinking water intake.

Direct effects of reduced TSS on aquatic biota relate to the subsequent increase in water clarity. Higher water clarity may serve as an advantage to visual predators and a disadvantage to prey items within this 10–12 km stretch of the lake. Increased water clarity may also affect primary producers through increases in light availability and depth of the euphotic zone; this pathway is characterized in Section 4.2.4.2.

2.5.2.3.5 Organic Carbon

Changes in OC are not expected to be detectable along the mainstem of the river upstream of Stephens Lake and concentrations flowing into Stephens Lake would therefore remain similar to existing conditions. Furthermore, TOC is comprised almost entirely of DOC and is not correlated to TSS concentrations (Figure 2H-40). Therefore, TOC and DOC would not be affected by decreased TSS concentrations in the 10–12 km area downstream of the Keeyask GS. No effects are expected in Stephens Lake, including the north arm of the lake or in the vicinity of the Gillam drinking water intake.

2.5.2.3.6 True Colour

As described for other variables, key changes in water quality expected upstream in the Keeyask reservoir are largely restricted to poorly mixed, isolated backbays. True colour is not expected to increase in the mainstem of the reservoir as a result of flooding and/or erosion. However, TSS and true colour are very weakly intercorrelated along the mainstem of the Nelson River (Figure 2H-39) and small reductions in true colour may occur downstream of the GS in Stephens Lake where TSS concentrations are expected to be decreased. As for other water quality variables, no effects to true colour are expected for the north arm of Stephens Lake or in the vicinity of the Gillam drinking water intake.

2.5.2.3.7 Water Clarity

Water clarity is expected to be increased in the 10–12 km stretch downstream of the GS, along the main flow of the Nelson River, due to predicted decreases in TSS due to Project operation. Neither TOC, DOC, nor true colour are expected to be measurably changed in Stephens Lake and therefore would not result in changes in water clarity. As for other water quality variables, no effects are expected for the north arm of Stephens Lake or in the vicinity of the Gillam drinking water intake.

2.5.2.3.8 Nutrients

As discussed for the Keeyask area, combined effects of flooding, peatland disintegration, and enhanced sedimentation are expected to cause a slight decrease in TP concentrations and a small, likely undetectable, increase in TN concentrations along the mainstem of the reservoir. TP may decrease due to predicted decreases in mineral TSS in the Keeyask reservoir (PE SV, Section 7) as TP is significantly correlated to TSS in the study area. Decreases in TP, relative to conditions without the Project, would be greatest under high flows. Therefore, the water entering the Stephens Lake area from the outflow of the GS will contain somewhat lower concentrations of phosphorus. These effects would be long-term as they result from changes in the hydrological regime and subsequent effects on sedimentation.

Furthermore, TSS is expected to decrease even further as water moves through Stephens Lake; this area would extend to approximately 10–12 km downstream of the GS (PE SV, Section 7). TP would therefore decrease further over this area. As TKN is not correlated to TSS (Figure 2H-41) and does not currently decrease in Stephens Lake in association with reductions in TSS and TP, TN concentrations should remain relatively consistent in Stephens Lake and similar to existing conditions. As for other water quality variables, no effects are expected for the north arm of Stephens Lake or in the vicinity of the Gillam drinking water intake.

In terms of trophic status, Stephens Lake is currently classified as meso-eutrophic to eutrophic and is expected to remain within a similar range of trophic status during the operation period. As the TP concentrations are currently near the boundary of these categories, phosphorus concentrations are expected to fall within either category from year to year.

2.5.2.3.9 Conductivity/Total Dissolved Solids

Conductivity/TDS are not expected to be measurably changed in Stephens Lake as a result of Project operation as no detectable changes are anticipated at the outflow of the GS.

2.5.2.3.10 Metals and Major Ions

With the possible exception of mercury, metals are not expected to be measurably increased in Nelson River water flowing out of the Keeyask GS. Concentrations of metals that are associated with suspended solids may in fact be slightly reduced in the outflow, notably under high flows, due to reductions in TSS (PE SV, Section 7). Metals that are positively correlated to mineral TSS (iron, aluminum, barium, chromium, cobalt, manganese, potassium, titanium, and vanadium) would likely be most notably affected. In addition, further reductions in total metal concentrations may occur over the 10–12 km stretch downstream of the GS due to reductions in mineral TSS, relative to current conditions. As noted in Section 2.5.2.11, it has been conservatively assumed that mercury and methylmercury concentrations may increase sufficiently to be detectable in the mainstem of the reservoir but both are expected to remain well below MWQSOGs and CCME PAL guidelines, and concentrations will decrease further in Stephens Lake.

2.5.2.4 Downstream Area

As discussed in the PE SV, Section 7, effects of the Project operation on TSS will not extend past Stephens Lake. In addition, effects on other water quality variables are expected to negligible beyond the area where effects to TSS are predicted. Therefore, no effects of Project operation on water quality are predicted for the Downstream area (*i.e.*, downstream of Stephens Lake).

2.5.2.5 North Access Road Stream Crossings

Due to implementation of sediment and erosion control measures, effects of the north access road on water quality during the operation period are expected to be negligible.

2.5.2.6 South Access Road Stream Crossings

Due to implementation of sediment and erosion control measures, effects of the south access road on water quality during the operation period are expected to be negligible.

2.5.3 Residual Effects

2.5.3.1 Construction Period

Residual effects of construction of the Keeyask Project on water quality are summarized in Table 2-22.

Key effects of construction are:

- Increased concentrations of TSS during instream construction, with the largest increases occurring immediately downstream of construction; and
- Increased concentrations of substances in effluents in the immediate receiving environment.

2.5.3.2 Operation Period

Residual effects of operation of the Keeyask Project on water quality are summarized in Table 2-23. Key effects of operation are:

- No effects to Split Lake;
- Short-term increases in TSS in nearshore areas and small to moderate long-term decreases in TSS in most areas of the reservoir and for a number of kilometres downstream of the reservoir;
- Nutrients, metals, organic carbon, true colour, conductivity/TDS will increase and pH and water clarity will decrease in nearshore areas due to flooding and peatland disintegration. Effects will be greatest in Year 1 and will decline thereafter;
- Dissolved oxygen concentrations will decrease in the ice-cover season in nearshore, flooded areas and anoxia will develop in some of the shallow, isolated areas over winter. Infrequent periods of low DO will develop in nearshore areas under atypically low wind conditions in summer. The majority of the reservoir will maintain DO concentrations above MWQSOGs and CCME guidelines for the protection of aquatic life year-round. Effects on DO will be greatest in Year 1 of operation and decline thereafter. Downstream effects will be negligible;
- Metals are expected to generally remain within MWQSOGs and CCME guidelines for the protection of aquatic life in the reservoir and downstream. The key exceptions are iron and aluminum, which are currently present at concentrations well above the MWQSOGs and CCME PAL guidelines and the Project operation will increase concentrations further. However, concentrations are expected to remain within the ranges of aluminum and iron concentrations in other Manitoba rivers or streams;
- Project operation is expected to cause or contribute to exceedances of MWQSOGs and CCME guidelines for PAL for selenium and silver, and potentially mercury and methylmercury in nearshore, flooded areas, most notably during the initial years of operation. The Project may also cause or contribute to exceedances of CCME PAL guidelines for cadmium, copper, and zinc but is not expected to cause exceedances of MWQSOGs for PAL for these metals;
- Project operation is expected to increase the magnitude by which the Manitoba/CCME aesthetic drinking water quality objectives for iron and true colour is exceeded in flooded backbays (both parameters are currently above the aesthetic objectives). As the Manitoba/CCME guidelines for turbidity in finished drinking water are extremely low (*i.e.*, 0.3/1.0/0.1 NTU, depending method of treatment), turbidity levels currently exceed these guidelines and these exceedances are expected to continue with the Project. All other water quality variables are expected to remain within Manitoba and CCME drinking water quality guidelines during the operating period;
- Project operation is expected to adversely affect the suitability of surface waters for recreational uses, in terms of changes to water quality, in the nearshore areas through increases in turbidity. However, currently, the suggested guideline for water clarity (minimum Secchi disk depth of 1.2 m) is typically not met and the Project operation is expected to result in increased water clarity on the main stem of the reservoir and over the long-term in nearshore areas;

- Effects of Project operation on water quality are generally expected to persist for 10–15 years, with the exception of effects on TSS (*i.e.*, a decrease) which will continue for the life-span of the Project; and
- Effects will extend to approximately 12–14 km downstream of the GS.

2.5.3.3 Summary of Residual Effects

The following summary of residual effects specifically addresses changes in relation to the suitability of water for aquatic life as specified in the MWQSOGs and CCME guidelines. Effects related to the use of water for recreation and drinking in the area affected by the Project are discussed in the SE SV. The residual effects of construction (Table 2-22) are expected to be adverse, short-term, and of moderate magnitude over a medium geographic extent at the construction site and in Stephens Lake, and be of small magnitude over a large geographic extent extending past the Kettle GS. During the initial years of operation, the Project will cause medium-term, moderate to large changes in water quality in nearshore areas of the reservoir (Table 2-23). There will be a moderate reduction in TSS in the reservoir and the southern portion of Stephens Lake in the long-term. Effects during operation are continuous/regular as they occur all the time or at regular intervals (*e.g.*, DO depletion each winter). Effects in flooded areas will diminish over time, while the decline in TSS levels is irreversible and will occur for the life of the Project. The ecological context of the predicted change is moderate, reflecting the importance of water quality to the aquatic ecosystem, but also the ability of the aquatic ecosystem to adapt to these changes and the diminishing effect over time.

The technical water quality assessment is based on models, scientific literature, and information collected from a proxy reservoir (*i.e.*, Stephens Lake) and the overall certainty associated with the predictions is moderate to high. Overall, there is high certainty regarding the nature and direction of all effects and the magnitude of effects predicted for the mainstem of the reservoir, and moderate certainty regarding the magnitude of effects in nearshore areas of the reservoir.

2.5.4 Environmental Monitoring and Follow-up

As described in Chapter 8 of the Keeyask Generation Project: Response to EIS Guidelines, Environmental Monitoring Plans are being developed as part of the Environmental Protection Program for the Project. The intent of the monitoring plans is to determine whether effects of the Project are as predicted and mitigation measures are functioning as intended. The monitoring plans will also provide for follow-up actions if effects are greater than predicted; the actions that would be taken depend on the nature and magnitude of the effect. The design of the monitoring plans will also consider uncertainties identified during the analysis and/or raised by the KCNs or during the regulatory review process. For example, the technical analysis predicts that effects to water quality will occur within the reservoir and downstream but that no effects will occur upstream in Split Lake; based on local knowledge, the KCNs have identified effects to Split Lake and therefore, Split Lake is being included in the monitoring program.

An outline of monitoring planned for the water quality component of the aquatic environment is provided below. A detailed monitoring plan will be provided in the Aquatic Effects Monitoring Plan

(AEMP). This document will provide a detailed description of the rationale, schedule, sampling locations and sampling methods for the technical monitoring that is proposed for the Project. This plan will be implemented in consultation with regulators, in particular DFO, Environment Canada, and Manitoba Conservation and Water Stewardship, and it is expected that it will change based on regulatory review and on-going review of monitoring results. This monitoring plan will be implemented during the construction phase of the Project and will continue into the operations phase. Reports detailing the outcomes of monitoring programs will be prepared and submitted to regulators, to meet conditions of the *Environment Act* licence and other authorizations for the Project.

Water quality monitoring will include sampling to measure site-specific effects such as inputs from flooded terrain, and targeted sampling of specific activities such as instream construction to determine the effectiveness of management measures such as the sediment management plan. Routine water quality monitoring will be conducted at sites along the Nelson River immediately downstream of the Kelsey GS to downstream of the Kettle GS.in order to verify that effects in the reservoir are not greater than anticipated and that effects do not extend upstream of the reservoir nor downstream of the GS (other than reduced suspended sediment concentrations). Sampling will occur multiple times during each year of construction and the initial 10 years after FSL is reached, and less frequently for the following 20–30 years, depending on results. For a more detailed description of planned water quality monitoring, please see the AEMP.

2.6 SEDIMENT QUALITY

2.6.1 Introduction

The quality of sediments, or the concentrations of sediment-associated chemicals, is of significance to the health of aquatic biota that live in or on sediments, or that directly or indirectly associate with the sediments and/or benthic communities. Potential effects of the Keeyask Project on sediment quality have been considered in terms of its suitability for aquatic life through comparisons to sediment quality guidelines (SQGs) and to the existing sediment quality in the area. A description of applicable SQGs applied for the assessment is provided in Section 2.6.2.4 and in greater detail in Appendix 2B.

The following sections provide:

- A description of approach and methods, including descriptions of information sources, models, and detailed approaches applied for evaluating the environmental setting and for the assessment of effects of the Project on sediment quality (Section 2.6.2);
- A description of the environmental setting for sediment quality, including an overview of historical information, a detailed description of current conditions, and an assessment of current trends (Section 2.6.3); and
- A description of the predicted effects of the Project on sediment quality associated with the construction and operation periods, a summary of residual effects, and proposed environmental monitoring and follow-up (Section 2.6.4).

2.6.2 Approach and Methods

The following sections provide a description of the general approach for the sediment quality assessment (Section 2.6.2.1), a brief description of the study area (Section 2.6.2.2), data and information sources used to describe and characterize the environmental setting (Section 2.6.2.3), and a description of the approach for the effects assessment (Section 2.6.2.4), including a description of assumptions and modelling approaches. The general approach and study area are similar to those applied for water quality.

2.6.2.1 Overview to Approach

Overall, the approach taken for the sediment quality effects assessment was similar to the general approach applied for other aquatic components. The assessment was comprised of two major components:

- A description of the existing sediment quality conditions in the study area to provide the foundation for assessing the potential effects of the Project; and
- An effects assessment in which potential effects of the Project on sediment quality are described.

The existing sediment quality conditions — or the "environmental setting" — were defined for a period of 10 years (1997–2006). Information used for this characterization was restricted to data gathered from sampling programs conducted under the Keeyask environmental studies (*i.e.*, EIS studies), as no other information could be located. Additionally, the environmental setting includes a description of historical information (*i.e.*, pre-1997) to provide an overview of how sediment quality conditions may have changed over time.

The effects assessment was founded on key linkages identified between the Project and sediment quality. Information sources used for the assessment included information generated through EIS studies, scientific literature pertaining to hydroelectric development and other reservoirs in Manitoba and elsewhere, and general supporting scientific literature.

Sediment quality conditions for the existing environment, as well as for predicted post-Project environmental conditions, were compared to SQGs for the protection of aquatic life (Persaud *et al.* 1993; BCMOE 2009; MWS 2011; CCME 1999; updated to 2012) to assist in characterizing the potential effects of the Project on aquatic biota.

2.6.2.2 Study Area

The study area for sediment quality ranges from the inflows to Split Lake to the Nelson River estuary and is consistent with the water quality study area (see Section 2.3.2).

2.6.2.3 Data and Information Sources

In general, information sources considered for the characterization of the environmental setting for sediment quality included:

- Pre-1997 studies;

- EIS-specific studies (1999–2006); and
- General scientific literature.

Supporting information used for characterizing the existing environment also included:

- MWQSOGs (MWS 2011);
- The CCME environmental quality guidelines (CCME 1999; updated to 2012);
- The BCMOE water quality guidelines (BCMOE 2009); and
- The Ontario Ministry of the Environment SQGs (Persaud *et al.* 1993).

2.6.2.3.1 Pre-1997 Studies

A limited number of environmental studies were conducted in the Aquatic Environment Study Area prior to 1997, including:

- Sediment quality was measured in Split Lake in 1979 by Williamson (1980) near the community of Split Lake, as well as at 23 other locations in northern Manitoba. Copper, zinc, cadmium, nickel, lead, and mercury were analysed in sediments varying from 1 to 3 cm in depth;
- Williamson (1986) measured mercury in upper (1–3 cm) sediments at 10 sites in northern Manitoba, including Split Lake, from 1980–1983; and
- Pip and Stepaniuk (1992) measured sediment quality upstream and downstream of the Limestone and Long Spruce GSs in 1988 (depth of sediment collected not reported).

2.6.2.3.2 Post-1996 Studies

Surficial sediment quality was measured at one site in each of Split, Gull, and Stephens lakes in the open water seasons of 2001 and 2002 (Map 2-24). Surficial sediments (upper 5 cm) were collected and analysed for particle size, organic matter, and metals. A detailed description of sampling sites, times, and methods and data analysis methods is provided in Appendix 2C. No other sediment quality data for the study area for the period of 1997–2006 were located.

2.6.2.4 Assessment Approach

2.6.2.4.1 Sediment Quality Guidelines

Throughout the document, comparisons are made between sediment quality and SQGs. There are Manitoba SQGs for a number of substances, including several metals/metalloids (MWS 2011), which were adopted from the CCME guidelines issued in 1999 (CCME 1999; updated to 2012). Two criteria are provided: (1) a sediment quality guideline; and (2) a higher value referred to as the **probable effect level** (PEL). The SQG is a threshold below which adverse effects to biota are expected to occur rarely whereas the PEL defines the level above which adverse effects are expected to occur frequently. Concentrations lying between the SQG and the PEL reflect a condition of increased risk of adverse effects. These criteria are intended to be applied to the upper 5 cm of sediment (CCME 1999; updated to 2012).

The province of Ontario (Persaud *et al.* 1993) has also issued SQGs for a number of substances in addition to those represented in the Manitoba or CCME SQGs. Similar to Manitoba and CCME guidelines, Ontario specifies a **lowest effect level** (LEL) and a **severe effect level** (SEL). The interpretation of these two thresholds is consistent with the Manitoba SQG and PEL. SQGs applied in this document are summarized in Appendix 2B.

Manitoba SQGs (MWS 2011) were considered for metals for which there are guidelines; as noted above, these SQGs are identical to the CCME guidelines. For additional parameters, guidelines applied by other jurisdictions in Canada were considered. Briefly, guidelines considered in the assessment were, in the following order:

- Manitoba SQGs (arsenic, cadmium, chromium, copper, lead, mercury, and zinc; MWS 2011);
- Ontario SQGs (iron, manganese, and nickel; Persaud *et al.* 1993); and
- British Columbia SQGs (selenium; BCMOE 2009).

2.6.2.4.2 Environmental Setting

The general approach applied for characterizing the existing sediment quality conditions in the study area involved compilation of existing data and information for the area and the conduct of baseline field studies to generate the information needed to support the impact assessment. Additionally, the environmental setting was detailed for both historic (pre-1997) and recent (1999–2006) time periods. Lastly, evaluation of trends in sediment quality for the study area was undertaken using existing information. Sediment quality conditions were described and compared to SQGs.

Analysis of Temporal Trends in Sediment Quality

For the purposes of the environmental assessment, an evaluation of potential temporal changes in sediment quality within the study area was undertaken to determine if conditions have undergone substantive change that could in turn affect the impact predictions and/or descriptions of the existing environment based on the period of the Keeyask environmental studies. Data characterizing sediment quality in the study area which could be used to infer temporal trends are limited. Therefore, the analysis was restricted to a qualitative comparison of historical and recent sediment quality data.

2.6.2.4.3 Project Assessment

Several approaches/information sources were used to describe anticipated effects of the Project on sediment quality, including:

- Scientific literature pertaining to Project linkage pathways;
- Peat chemistry data for the study area (PE SV, Section 7); and
- Information generated from other EIS components (*i.e.*, sedimentation; PE SV, Section 7; Section 3.4.2).

Potential effects of the Keeyask Project on sediment quality were assessed by integrating several pieces of information respecting the existing sediment quality, quality of peat that would be flooded, and predicted effects to sedimentation and changes in substrate.

To assess potential effects of flooding on sediment quality, information describing peat quality for the flooded area was compared to information describing the current sediment quality of the existing environment. Total metals were analysed in 61 peat samples collected at 37 sites (TE SV Appendix 2A 2.15.2). "Surface peat" samples (defined as the upper 20 cm) were collected from 20 sites and samples from the Of (*i.e.*, **fibric peat**), Om (*i.e.*, **mesic peat**), and Oh horizons (*i.e.*, **humic peat**) were collected from 17 sites and submitted to an accredited analytical laboratory for analysis of total metals. To determine the sediment quality in the newly flooded areas, the peat chemistry data were statistically summarized and compared to existing sediment quality and to SQGs.

SQGs are generally applied to the upper 5 cm of sediment (*e.g.*, CCME 1999; updated to 2012), in consideration of the area most actively used by aquatic biota. Therefore, the surface peat layer is the most biologically relevant layer. However, as peat resurfacing is expected in some flooded areas (PE SV, Section 7), other depth horizons of peat will be exposed and form new "sediment". As such, the assessment considers the chemistry of both surface peat and underlying depth horizons.

Additionally, predicted rates of mineral and organic sedimentation, as well as areas of deposition (PE SV, Section 7; Section 3.4.2.2), were considered to describe the potential temporal changes in sediment quality associated with the Project.

A detailed description of the characterization of the magnitude of effects to sediment quality is provided in Appendix 2G.

2.6.3 Environmental Setting

The following provides a description of sediment quality for the study area, considering each of the areas described in Section 2.2.3.2. The discussion provides:

- An overview of published literature describing historical sediment quality conditions for the study area (Section 2.6.3.1).
- A summary of sediment quality data collected in the study area under the Keeyask environmental studies over the period of 1997–2006 (Section 2.6.3.2);
- A description of sediment quality in a regional context (Section 2.6.3.3); and
- A discussion of potential temporal changes in sediment quality for the study area (Section 2.6.3.4).

2.6.3.1 Pre-1997 Conditions

Two historical studies of sediment quality in Split Lake were located. Williamson (1980) measured sediment quality at 24 sites in northern Manitoba, including Split Lake (Table 2I-1). The author concluded that concentrations of copper, zinc, cadmium, nickel, lead, and mercury were within "normal expected background". Data were not compared to SQGs as none were available at that time.

Comparison of the data obtained from both of these sites to current Manitoba, CCME and Ontario SGQs indicates that concentrations of copper, zinc, and lead were below guidelines but mean cadmium concentrations in sediments collected from Split Lake exceeded the Manitoba/CCME SQG. Additionally, the mean concentration of nickel in Split Lake exceeded the Ontario LEL for sediment. It is noteworthy that cadmium exceeded the SQG at all 24 sites examined and nickel exceeded sediment quality guidelines at all but three of the sites analyzed by Williamson (1980).

In a later study, Williamson (1986) stated that "All concentrations [of mercury measured in surficial sediments collected in Split Lake from 1979–83] were found to be within the range of 'naturally-occurring' mercury in bed sediments" (Appendix 2I) and there was "little apparent change [in Hg in sediments] at all sampling sites throughout the duration of the investigation." Sediment mercury concentrations reported in these two studies were below the current Manitoba SQG for the protection of aquatic life (Table 2I-2).

Only one report was located in which sediment quality was reported downstream of Split Lake prior to 1997. Pip and Stepaniuk (1992) measured cadmium, lead, and copper in surficial sediments collected in macrophyte beds located upstream and downstream of the Long Spruce and Limestone GSs. Sites included sampling of tributaries, some of which were deemed representative of areas "unaffected by flooding from water level changes, or other direct impacts associated with the dams." The authors reported that lead and cadmium were not significantly different at sites located upstream and downstream of the Limestone and Long Spruce GSs but mean copper was higher downstream of both dams. The authors also noted that particle size of sediments increased with the number of dams (*i.e.*, downstream). However, raw sediment quality data were not presented.

2.6.3.2 Current Conditions (Post-1996)

Of those parameters for which there are Manitoba SQGs, concentrations of arsenic, cadmium, copper, mercury, and zinc were within guidelines in Split, Gull, and Stephens lakes. Chromium and lead were also within the Manitoba SQG in Split and Gull lakes (Table 2-24). The mean of triplicate samples collected from Stephens Lake in 2002 exceeded the Manitoba SQG for chromium and the Manitoba PEL for lead. The latter is a result of a single high value measured in one of the replicate samples and may represent an anomaly.

Comparison to Ontario SQGs indicates that concentrations of manganese and nickel exceeded the Ontario LEL but not the SEL in Split and Stephens lakes; lower concentrations were observed in Gull Lake. Nickel exceeded the LEL but not the SEL in 2002 but not 2001 in Gull Lake. Iron exceeded the Ontario LEL in 2002 but not 2001 in Stephens Lake but was below the LEL in Split and Gull lakes. Selenium was consistently below the BCMOE SQG.

2.6.3.3 Regional Context

Sediment quality was measured at Notigi, Wapisu, Wuskwatim, Opegano and Birch Tree lakes and the Burntwood River (near Taskinigup Falls) in 2001/2002 (Table 2I-3). Most sediment quality parameters measured in Split, Gull, and Stephens lakes in 2001/2002 are similar to or lower than values obtained from the Burntwood River system in the same years. Notable exceptions include calcium (except Gull

Lake in 2001), lead from Stephens Lake in 2002, magnesium in Split and Stephens lakes, and molybdenum in Gull and Stephens lakes in 2002 which were somewhat higher than samples from the Burntwood River system.

2.6.3.4 Current Trends

As indicated in Section 2.6.3.3, sediment quality has been measured at a number of sites in northern Manitoba beginning in the 1970s (Williamson 1980, 1986). Bodaly *et al.* (1987) also reported mercury concentrations for upper (approximately 4.7 cm) sediments collected from selected lakes along the CRD route in 1981 (Table 2I-4). In general, metal concentrations measured in the study area in 2001/2002 are lower than concentrations reported for sediments collected from Split Lake in 1979 (Table 2I-1). Observed differences may represent natural variability, differences in sampling methods and analysis, and/or actual decreases since 1979. Regardless of whether these data represent a true decrease in concentrations, with the exception of cadmium, values obtained in 1979 were also below current Manitoba SQGs as they were in 2001/2002 in Split Lake. The reported concentration of cadmium in 1979 exceeded the current SQG although this may reflect lower levels of accuracy and precision for the analytical methods used at that time.

Similarly, mercury concentrations measured in Split Lake in 2001 were similar to or lower than those measured from 1979–1983 in the lake. Furthermore, concentrations of mercury measured in Split, Gull, and Stephens lakes in 2001 were similar to or lower than concentrations measured at a number of sites across northern Manitoba in 1979–1983 (Appendix 2I; Williamson 1986; Bodaly *et al.* 1987).

Collectively, the available data indicate that sediment quality conditions in the study area since the late 1970s and early 1980s are similar to or potentially better than observed several decades ago.

2.6.4 Project Effects, Mitigation, and Monitoring

2.6.4.1 Construction Period

The potential linkages between the Project construction and effects on sediment quality are directly related to effects on water quality. Construction-related effects on water quality may affect sediment quality through accumulation of contaminants in sediments. A description of the linkages between water quality and Project construction is provided in Section 2.5.1.

Negligible to small effects on sediment quality are expected as a result of Project construction due to the implementation of various mitigation measures designed to minimize the introduction of nutrients, metals, and other contaminants to surface waters. Localized changes in sediment quality may occur in the vicinity of point source discharges (e.g., treated sewage effluent outfall).

2.6.4.2 Operation Period

Sediment quality may be affected in the study area during the operation period through various pathways, including:

- Changes to the water regime, water residence times, water depths, and water velocities which may alter sedimentation processes and depositional areas;
- Flooding of terrestrial habitat will create "new" aquatic sediments;
- Erosion of mineral and organic soils, leading to changes in TSS and alterations to sedimentation rates and patterns; and
- Changes in water quality conditions may alter conditions at the sediment-water interface which, in turn, may affect sediment processes/chemistry and decomposition processes (*e.g.*, anaerobic decay processes may dominate under anoxic conditions).

The following is an assessment of the potential effects of the Project on sediment quality, emphasizing changes with respect to SQGs for the protection of aquatic life. Changes in substrates related to physical habitat are discussed in Section 3.0.

No effects to sediment quality are expected in the Split Lake Area as flooding, changes in TSS and sedimentation, and effects on water quality are not expected in this area.

Results of analyses of key variables measured in peat and existing sediments are presented in Figure 2-17 to Figure 2-30 for comparison. Most metals are present at lower concentrations in peat in both surface and sub-surface horizons than in the existing sediments in the study area. All concentrations of metals in peat samples were also below SQGs for the protection of aquatic life and therefore, flooding (*i.e.*, conversion of peat to aquatic sediments) should not result in an exceedance of SQGs.

Metals that are present in higher concentrations in peat than aquatic sediments in the study area include: mercury (Figure 2-25); cadmium (Figure 2-19); lead (Figure 2-23); potassium (Figure 2-29); and sodium (Figure 2-30). In addition, direct comparison between sediments and peat cannot be reliably made for arsenic (Figure 2-18) and selenium (Figure 2-27) due to higher analytical DLs employed for the analysis of peat. The following provides a brief discussion for these substances.

While still below SQGs, mercury is approximately fifteen times higher in surface peat than in current sediments in Gull Lake (Figure 2-25). However, the mean concentration measured in surface peat is similar to concentrations of mercury measured in 1981–82 in unflooded peat adjacent to lakes along the CRD and in flooded peat in lakes along the CRD (Bodaly *et al.* 1987; Table 2-25). Higher concentrations of mercury in organic materials relative to the more mineral sediments are expected as mercury has a high affinity for organic matter in soils and sediments (Mucci *et al.* 1995). Collectively, these data indicate that flooding may introduce a larger quantity of total mercury into the aquatic ecosystem than is currently present in the sediments, but the concentrations measured in peat from the Keeyask area are similar to concentrations measured in other peatland areas of northern Manitoba.

While the mean concentration of mercury in surface peat is below the Manitoba SQG for the protection of aquatic life and is therefore of low risk from a toxicity perspective, it is expected that flooding will result in a greater production of methylmercury due to stimulation of the methylation process. Therefore, the substrate and nutrients made available for mercury methylating bacteria as a result of flooding, in conjunction with a relatively higher concentration of mercury available in that substrate, is expected to enhance methylmercury production in sediments. This has been observed in numerous other newly created reservoirs (*e.g.*, Bodaly *et al.* 1984b; Hecky *et al.* 1987a; Mucci *et al.* 1995; Kelly *et al.* 1997; Heyes *et al.* 2000) and is a typical effect of flooding. Concentrations of methylmercury are related to the amount and type of organic matter in flooded soils. For example, concentrations of methylmercury in flooded soils at the La Grande-2 reservoir in Quebec paralleled the distribution of organic carbon (Mucci *et al.* 1995). Methylation is also generally higher under anoxic conditions (*e.g.*, Matilainen 1995; Heyes *et al.* 2000), which are expected to occur in some nearshore areas of the Keeyask reservoir in winter. The effects of the Project on mercury in fish are discussed in Section 7.

The second metal that is higher in peat than existing sediments is cadmium (Figure 2-19). The mean surface peat concentration (0.397 micrograms per gram [µg/g]) is approximately seven times the mean concentration of Gull Lake sediments (0.06 µg/g; Figure 2-19). However, the mean concentration in peat is similar to concentrations measured in sediments from Notigi, Wapisu, Wuskwatim, Opegano, and Birch Tree lakes in 2001 and 2002 (Table 2I-3). Most notably, the mean peat concentration is below the Manitoba SQG (0.6 µg/g). Therefore, on average, cadmium should not pose a risk to aquatic biota in sediments. It is noted, however, that some spatial variability in the cadmium content of flooded peat may result in localized exceedances of the SQG as some individual measurements were above the SQG in peat. However, the highest measured concentration of cadmium in peat (0.847 µg/g) is well below the Manitoba PEL (3.5 µg/g), which is the threshold above which adverse effects are expected to occur frequently.

Other substances that are higher in surface peat than aquatic sediments include: lead (Figure 2-23); potassium (Figure 2-29); and sodium (Figure 2-30). However, the mean concentrations of these substances in surface peat were within the observed range of concentrations measured in sediments across study sites and years. That is, average levels fall within existing conditions and, in the case of lead, are most notably below SQGs.

For two substances, arsenic and selenium, the available information is insufficient to quantitatively compare peat quality to existing sediment quality due to differences in analytical DLs. In the case of arsenic, the mean peat concentration was below the analytical DL (4 µg/g), although arsenic was detected in some samples. The DL for arsenic in peat was higher than the mean concentration measured in sediment in 2001 (1.08 µg/g), but the mean concentration of arsenic measured in sediments in 2002 (4.46 µg/g) was higher than the DL for peat. When detected in peat (*i.e.*, concentrations above the DL of 4 µg/g), concentrations of arsenic were therefore somewhat higher than sediment concentrations. Overall, it appears that the concentration of arsenic in peat is similar to or possibly somewhat higher than that of the existing sediments. Regardless, the applicable DL for the analysis of arsenic in peat was below the SQG for the protection of aquatic life and therefore, arsenic should not pose a risk to aquatic biota.

Similarly, selenium was not detected in peat samples, but due to the relatively high analytical DL (10 µg/g) direct comparison to SQGs cannot be made. On the basis of the higher analytical DL, it must be assumed that selenium may be higher in peat than in current sediments. While there are no SQGs for selenium in Manitoba, the DL employed for the analysis of selenium in Keeyask peat samples is above the BCMOE SQG of 2.0 µg/g. However, the BCMOE SQG is intended to be adjusted for the percent of TOC; the SQG increases with increasing TOC. Although the concentration of TOC in Keeyask peat samples is not known, it is likely above the default TOC concentration of 5% for the SQG of 2.0 µg/g. Therefore, concentrations of selenium in peat may be below the applicable SQG based on TOC content. In addition, concentrations in peat may be similar to those in aquatic sediments, but the available information is insufficient for comparison.

Flooded organic peat substrates will gradually become covered with mineral sediment over the operation period. By approximately Year 30 of operation, the majority of the sediments in the reservoir will be mineral, with localized pockets of organic substrates persisting near the mouths of small tributaries (Section 3). Therefore, sediment quality will evolve over time to more closely resemble current sediment quality in most of the reservoir.

No effects to sediment quality are expected in the Stephens Lake area or downstream as flooding is restricted to the Keeyask area and areas that are currently sedimentary will continue to be sedimentary with the Project (PE SV, Section 7).

2.6.4.3 Residual Effects

2.6.4.3.1 Construction Period

Residual effects of construction of the Keeyask Project on sediment quality are summarized in Table 2-26. Effects are expected to be negligible.

2.6.4.3.2 Operation Period

Residual effects of operation of the Keeyask Project on sediment quality are summarized in Table 2-27. Effects are predicted to be negligible in all areas except the Keeyask reservoir, where flooding of terrestrial soils and peat may lead to small increases in mercury concentrations in sediments until Year 30, but overall levels are expected to remain below the Manitoba Sediment Quality Guidelines.

2.6.4.3.3 Summary of Residual Effects

The residual effects of construction are expected to be negligible (Table 2-26). During the first 30 years of operation, the Project will cause frequent, long-term, negligible to small changes in sediment quality over a small geographic extent (*i.e.*, in newly-flooded nearshore areas) (Table 2-27). Despite the potential for increased mercury concentrations in nearshore sediments, total mercury values are not expected to exceed Manitoba Sediment Quality Guidelines. These effects to sediment quality are not reversible. The technical sediment quality assessment is based on scientific literature and information collected from a proxy reservoir (*i.e.*, Stephens Lake) and the overall certainty associated with the predictions is high.

2.6.4.4 Environmental Monitoring and Follow-up

No monitoring of sediment quality is required.

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TABLES, FIGURES, AND MAPS

Table 2-1: Water quality variables discussed in the EIS and rationale for their inclusion

Water Quality Category	Indicators	Linkage to the Project	Importance of Variables
Nitrogen, phosphorus, carbon, chlorophyll *a*	Total Kjeldahl nitrogen; Ammonia; Nitrate/nitrite; Total nitrogen; Total phosphorus; Total dissolved phosphorus; Total organic carbon; Dissolved organic carbon; and Chlorophyll *a*.	Flooding and decomposition of organic materials may introduce nutrients to the water column; Erosion of mineral or organic soils may increase nutrient concentrations in aquatic ecosystems; Changes in water regime (*e.g.*, reduced velocities) may affect settling/suspension of particulate materials; and Chlorophyll *a* (an indicator of phytoplankton abundance) is included as a supporting variable (for interpretation of nutrient information). Phytoplankton is discussed in detail in Section 4.	Excessive nutrients may lead to increased primary production (which may then lead to other trophic effects); Eutrophication may be associated with larger or more frequent algal blooms, development of noxious algal blooms, dissolved oxygen issues, production of algal toxins, taste and odour issues, and reduced aesthetic quality; and There is a narrative water quality guideline for nutrients in MB and a CCME phosphorus guidance framework for the management of freshwater systems.
Water clarity	Total suspended solids; Turbidity; True colour; DOC; Secchi disk depth; and Light extinction.	Changes in velocities, depths, and residence times may affect settling of particulate materials; Erosion of mineral soils and disintegration of peat may increase TSS and related parameters; and Flooding and decomposition of organic materials may increase water colour and DOC and affect light properties.	Water clarity and colour affect the availability and quality of light in surface waters, which in turn affect primary producers. Reducing water clarity can lead to lower levels of plant or algal growth; The colour and transparency of water also affects behaviour and survival/growth/condition of some biota (*e.g.*, reducing predation success of visual predators; increased survival of fish due to reduced acuity of predators); Total suspended solids may be harmful to aquatic

Table 2-1: Water quality variables discussed in the EIS and rationale for their inclusion

Water Quality Category	Indicators	Linkage to the Project	Importance of Variables
			life; There are water quality objectives/guidelines for the protection of aquatic life for total suspended solids; Reduced water clarity may affect navigation; Turbidity/total suspended solids may affect the efficacy of water treatment facilities; There are aesthetic drinking water quality guidelines for colour and health-based guidelines for turbidity; and There are recreational water quality guidelines for water clarity.
Water salinity	Total dissolved solids; and Specific conductance.	The amount of dissolved materials (i.e., salinity) in water may be affected by flooding.	High levels of dissolved solids can be harmful to freshwater aquatic life; Used as a general indicator of changes in water quality; and There is an aesthetic objective for drinking water quality for total dissolved solids.

Table 2-1: Water quality variables discussed in the EIS and rationale for their inclusion

Water Quality Category	Indicators	Linkage to the Project	Importance of Variables
Metals/metalloids	Metals; and Hardness.	Changes in velocities, depths, and residence times may affect settling of particulate materials and thus metals bound to particulate materials; Erosion of mineral soils and disintegration of peat may increase TSS and particulate-bound metals; Decomposition of flooded peat may affect concentrations of metals in water; Hardness is a supporting variable (water quality objectives for some metals are dependent on water hardness); and Flooding and decomposition may stimulate production of methylmercury and subsequent bioaccumulation.	Metals/metalloids include some essential elements (*e.g.*, calcium) and non-essential elements (*e.g.*, arsenic); Many metals/metalloids can be toxic to aquatic life, wildlife, or humans; and There are water quality objectives and guidelines for the protection of aquatic life and drinking water for numerous metals/metalloids.
pH and alkalinity	pH; Total alkalinity; Bicarbonate alkalinity; Hydroxide alkalinity; and Carbonate alkalinity.	pH may be reduced due to flooding and decomposition of organic materials; and May be indirect effects related to Project-induced changes in algal abundance.	High or low pH may be harmful to aquatic life; pH may have aesthetic effects on drinking water; There are water quality guidelines for pH for the protection of aquatic life and recreation and aesthetic objectives for drinking water; and pH may affect the cycling and forms of other substances in water.

Table 2-1: Water quality variables discussed in the EIS and rationale for their inclusion

Water Quality Category	Indicators	Linkage to the Project	Importance of Variables
Dissolved oxygen	Dissolved oxygen; and Temperature.	Decomposition of flooded organic materials may reduce dissolved oxygen; Decomposition of eroded/disintegrated peat may reduce dissolved oxygen; Changes in water regime/morphometry may affect DO (*e.g.*, water velocities, depths, fetch, residence times); Changes in the ice regime may affect DO (*i.e.*, changes in the duration and extent of ice cover); Changes in primary production may affect DO (*i.e.*, diurnal DO swings, DO depletion during senescence of primary producers); and Water temperature is considered as it closely relates to dissolved oxygen saturation, stratification/mixing, and to the presence of early or mature life stages.	Dissolved oxygen is essential for most forms of aquatic life; DO may affect the cycling of other substances in water (*e.g.*, precipitation/release of iron from sediments); and There are water quality objectives/guidelines for the protection of aquatic life.
Bacteria and Parasites	Fecal coliform bacteria; *Giardia* sp.; and *Cryptosporidium* sp.	Coliform bacteria may be increased by introduction of treated sewage effluent.	Coliform bacteria may affect the suitability of aquatic ecosystems for recreation and drinking water quality; and There are water quality guidelines/objectives for recreation and drinking water.

Table 2-2: Summary of key variables (means) measured in the study area and at several Manitoba Water Stewardship monitoring sites in northern Manitoba

Sites	TP (mg/L)	TKN (mg/L)	pH (Laboratory)	Total Alkalinity (mg/L as $CaCO_3$)	TSS (mg/L)	Turbidity (NTU)	True Colour (TCU)	TDS (mg/L)	Specific Conductance [4] (µS/cm)	TOC (mg/L)	Hardness (as $CaCO_3$) (mg/L)	Total Aluminum (mg/L)	Total Iron (mg/L)	Chlorophyll *a* (µg/L)	Data Period
Mainstem Sites [1]															
SPL3	0.040	0.4	8.05	-	17	37	-	-	154	9	-	-	-	4	2001–2003
SPL4	0.038	0.5	8.14	-	12	25	-	-	291	8	-	-	-	6	2001–2003
SPL5	0.030	0.6	7.97	-	8	14	-	-	205	13	-	-	-	6	2001–2003
SPL6	0.037	0.5	8.15	-	12	27	-	-	285	9	-	-	-	7	2001–2003
SPL7	0.038	0.5	8.13	89	14	28	35	167	250	9	104.3	1.44	1.04	6	2001–2004
SPL8	0.039	0.5	8.11	89	15	29	21	163	245	8	103.3	1.46	0.94	6	2001–2004
SPL9	0.034	0.4	8.24	104	14	18	18	195	313	8	124.5	1.18	0.74	6	2004
YL1	0.033	0.6	8.13	93	8	17	31	169	270	10	107.4	0.97	0.58	5	2002–2004
CL1	0.040	0.5	8.14	96	15	28	19	178	258	9	114.0	1.52	0.92	6	2001–2004
NR1	0.039	0.4	8.13	-	16	28	-	-	252	8	-	-	-	5	2001–2004
NR2	0.038	0.5	8.11	91	16	28	26	168	257	8	110.8	1.50	1.12	6	2001–2004
GL1	0.039	0.5	8.07	-	15	31	-	-	251	9	-	-	-	6	2001–2003
GL2	0.039	0.5	8.10	-	15	31	-	-	258	8	-	-	-	6	2001–2003
Camp 1	0.045	0.5	8.18	87	18	35	43	153	244	9	106.6	1.94	1.39	5	2003
Camp 2	0.043	0.5	8.23	85	15	33	41	153	245	9	103.5	1.45	1.06	5	2003
STL1	0.037	0.5	8.16	92	15	28	26	178	260	9	107.8	1.42	0.98	6	2001–2004
STL2	0.034	0.5	8.12	-	11	24	-	-	255	8	-	-	-	5	2001–2004
GT1	0.036	0.4	8.17	89	10	22	28	158	252	9	105.7	1.24	0.84	6	2002–2004
NR3	0.033	0.4	8.14	-	10	21	-	-	252	9	-	-	-	6	2002–2004
NR4	0.032	0.5	8.13	89	9	20	26	157	252	8	101.1	1.18	0.77	5	2002–2004
NR5	0.030	0.4	8.24	91	8	19	28	159	248	9	102.3	0.99	0.63	4	2002–2004
NR6	0.032	0.4	8.15	91	9	18	23	162	251	9	102.1	1.08	0.71	5	2002–2004
NR7	0.037	0.4	8.20	-	13	24	-	-	254	9	-	-	-	6	2002–2004
NR8	0.033	0.4	8.25	-	14	23	-	-	252	9	-	-	-	6	2002–2004
Off-system Sites [1]															
STL3 (North Arm of Stephens Lake)	0.016	0.4	8.19	-	7	10	-	-	281	8	-	-	-	2	2004
AL1	0.023	0.4	8.19	-	9	13	-	-	209	10	-	-	-	3	2001–2003
AL2	0.020	0.5	8.07	-	4	6	-	-	184	11	-	-	-	3	2001–2003

Table 2-2: Summary of key variables (means) measured in the study area and at several Manitoba Water Stewardship monitoring sites in northern Manitoba

Sites	TP (mg/L)	TKN (mg/L)	pH (Laboratory)	Total Alkalinity (mg/L as $CaCO_3$)	TSS (mg/L)	Turbidity (NTU)	True Colour (TCU)	TDS (mg/L)	Specific Conductance [4] (µS/cm)	TOC (mg/L)	Hardness (as $CaCO_3$) (mg/L)	Total Aluminum (mg/L)	Total Iron (mg/L)	Chlorophyll *a* (µg/L)	Data Period
Large Tributaries [1]															
SPL1 (Burntwood River)	0.040	0.4	8.02	57	19	37	48	91	121	8	59.7	1.85	1.43	4	2001–2004
SPL2 (Nelson River at Split Lake)	0.038	0.5	8.14	104	13	23	20	198	302	8	123.2	1.20	0.77	6	2001–2004
AK1 (Aiken River)	0.026	0.8	7.79	77	7	6	66	118	160	17	83.1	0.31	0.33	5	2002–2003
LR-1 (Limestone River)	0.014	0.4	8.22	-	3	3	-	-	272	14	-			2	2002–2004
AR-1 (Angling River)	0.012	0.5	8.05	-	2	2	-	-	157	15	-	-	-	2	2002–2004
WR-1 (Weir River)	0.014	0.4	8.15	-	4	3	-	-	228	15	-	-	-	2	2002–2004
Small Tributaries [1]															
TRIB-1 (Two Goose Creek)	0.013	0.4	7.71	-	<2	2	-	-	141	16	-	-	-	1	2003–2004
TRIB-2 (Portage Creek)	0.020	0.6	7.67	-	2	3	-	-	125	18	-	-	-	2	2003–2004
TRIB-3 (Rabbit Creek)	0.016	0.6	7.61	-	2	4	-	-	168	23	-	-	-	2	2003–2004
BC-1 (Beaver Creek)	0.008	0.5	7.85	-	2	2	-	-	149	23	-	-	-	<1	2004
SCK-1 (Swift Creek)	0.008	0.4	7.95	-	<2	1	-	-	177	16	-	-	-	<1	2004
TC-1 (Tiny Creek)	0.010	0.5	7.88	-	4	3	-	-	133	21	-	-	-	<1	2004
GC-1 (Goose Creek)	0.005	0.5	7.98	-	<2	1	-	-	146	19	-	-	-	<1	2004
15C-1 (Creek #15)	0.007	0.5	7.73	-	<2	1	-	-	104	21	-	-	-	<1	2004
Regional Sites [2]															
Burntwood River at Thompson	0.060	0.4	7.79	56	17	29	43	94	119	8	58	1.41	1.30	-	1997–2006
Nelson River at Sipiwesk Lake Outflow	0.045	0.5	7.94	102	11	16	22	188	304	8	118	0.71	0.58	-	1997–2006
Churchill River Upstream of Granville Lake	0.024	0.3	7.43	35	5	6	16	56	96	8	33	0.33	0.29	-	1997–2006
Split Lake near the Community of Split Lake	0.049	0.4	7.91	93	14	21	28	169	263	8	107	0.91	0.79		1997–2006
Hayes River [3]	0.020	0.5	7.94	80.4	12	11	44	88	140	12	82	0.32	0.50	-	1993–1995

Note: Data represent samples collected in the open water period only.

TP = total phosphorus, TKN = total Kjeldahl nitrogen, TSS = total suspended solids, TDS = total dissolved solids, TOC = total organic carbon.

1. Data from this study.
2. Data provided by Manitoba Water Stewardship.
3. Data provided by Environment Canada.
4. *In situ* data (this study) and laboratory data (Regional sites).

Table 2-3: Canadian Council of Resource and Environment Ministers (CCREM 1987) classification scheme for water hardness of surface waters

Hardness as calcium carbonate (mg/L)	Degree of Hardness
0–30	Very soft
31–60	Soft
61–120	Moderately soft (hard)
121–180	Hard
180+	Very Hard

Table 2-4: Saffran and Trew (1996) categorization of acid sensitivity of aquatic ecosystems

Parameter	Units	Acid Sensitivity			
		High	Moderate	Low	Least
pH		<6.5	6.6–7.0	7.1–7.5	>7.5
Total Alkalinity	mg/L (as $CaCO_3$)	0–10	11–20	21–40	>40
Calcium	mg/L	0–4	5–8	9–25	>25
Total dissolved solids	mg/L	0–50	51–200	201–500	>500

Table 2-5: **Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic categories for freshwater aquatic ecosystems based on total phosphorus (TP; µg/L), and mean concentrations of TP measured across the study area (2001–2004 open water seasons). Mean TP concentrations for three Manitoba Water Stewardship (MWS) water quality monitoring sites in northern Manitoba (1997–2006 open water seasons) are also provided for context**

CCME Trophic Categories	Lake Trophic Status (CCME 1999; updated to 2012)							Years Sampled
	Ultra-oligotrophic	Oligotrophic	Oligo-mesotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic	
	<4	4–10	-	10–20	20–35	35–100	>100	
Mainstem Sites								
SPL3						40		2001–2003
SPL4						38		2001–2003
SPL6						37		2001–2003
SPL7						38		2001–2004
SPL8						39		2001–2004
CL1						40		2001–2004
GL1						39		2001–2003
GL2						39		2001–2003
NR1						39		2001–2004
NR2						38		2001–2004
Camp 1						45		2003
Camp 2						43		2003
STL1						37		2001–2004

Table 2-5: Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic categories for freshwater aquatic ecosystems based on total phosphorus (TP; µg/L), and mean concentrations of TP measured across the study area (2001–2004 open water seasons). Mean TP concentrations for three Manitoba Water Stewardship (MWS) water quality monitoring sites in northern Manitoba (1997–2006 open water seasons) are also provided for context

	Lake Trophic Status (CCME 1999; updated to 2012)							
CCME Trophic Categories	**Ultra-oligotrophic**	**Oligotrophic**	**Oligo-mesotrophic**	**Mesotrophic**	**Meso-eutrophic**	**Eutrophic**	**Hyper-eutrophic**	**Years Sampled**
	<4	**4–10**	**-**	**10–20**	**20–35**	**35–100**	**>100**	
STL2					34			2001–2004
GT1						36		2002–2004
NR3					33			2002–2004
NR4					32			2002–2004
NR5					30			2002–2004
NR6					32			2002–2004
NR7						37		2002–2004
NR8					33			2002–2004
Off-current Sites								
SPL5					30			2001–2003
YL1					33			2002–2004
STL3				16				2004
Tributaries								
AL1					23			2001–2003

Table 2-5: Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic categories for freshwater aquatic ecosystems based on total phosphorus (TP; µg/L), and mean concentrations of TP measured across the study area (2001–2004 open water seasons). Mean TP concentrations for three Manitoba Water Stewardship (MWS) water quality monitoring sites in northern Manitoba (1997–2006 open water seasons) are also provided for context

	Lake Trophic Status (CCME 1999; updated to 2012)							
CCME Trophic Categories	**Ultra-oligotrophic**	**Oligotrophic**	**Oligo-mesotrophic**	**Mesotrophic**	**Meso-eutrophic**	**Eutrophic**	**Hyper-eutrophic**	**Years Sampled**
	<4	**4–10**	**-**	**10–20**	**20–35**	**35–100**	**>100**	
AL2				20				2001–2003
SPL1						40		2001–2004
SPL2						38		2001–2004
SPL9					34			2004
AK1					26			2002–2003
TRIB-1				13				2003–2004
TRIB-2				20				2003–2004
TRIB-3				16				2003–2004
LR-1				14				2002–2004
AR-1				12				2002–2004
WR-1				14				2002–2004
BC-1		8						2004
SCK-1		8						2004
TC-1		10						2004

Table 2-5: **Canadian Council of Ministers of the Environment (CCME 1999; updated to 2012) trophic categories for freshwater aquatic ecosystems based on total phosphorus (TP; µg/L), and mean concentrations of TP measured across the study area (2001–2004 open water seasons). Mean TP concentrations for three Manitoba Water Stewardship (MWS) water quality monitoring sites in northern Manitoba (1997–2006 open water seasons) are also provided for context**

	Lake Trophic Status (CCME 1999; updated to 2012)							
CCME Trophic Categories	**Ultra-oligotrophic**	**Oligotrophic**	**Oligo-mesotrophic**	**Mesotrophic**	**Meso-eutrophic**	**Eutrophic**	**Hyper-eutrophic**	**Years Sampled**
	<4	**4–10**	**-**	**10–20**	**20–35**	**35–100**	**>100**	
GC-1		5						2004
15C-1		7						2004

Table 2-6: Detection frequencies exceedance for metals measured in the study area: 2001–2006

Sample Location	Location ID		Aluminum (mg/L)	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Bismuth (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Calcium (mg/L)
Burntwood River	SPL-1	# Samples	12	12	12	12	12	4	12	12	12
		# Detected	12	0	4	12	0	0	1	1	12
		% Detected	100	0	33	100	0	0	8	8	100
Upper Nelson River	SPL-9	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	4	0	4	4	0	0	3	0	4
		% Detected	100	0	100	100	0	0	75	0	100
Upper Nelson River	SPL-2	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	4	0	4	4	0	0	3	2	4
		% Detected	100	0	100	100	0	0	75	50	100
Aiken River	AK-1	# Samples	8	8	8	8	8	0	8	8	8
		# Detected	8	0	3	8	0	-	0	2	8
		% Detected	100	0	38	100	0	-	0	25	100
Split Lake	SPL-5	# Samples	1	1	1	1	1	1	1	1	1
		# Detected	1	0	1	1	0	1	0	0	1
		% Detected	100	0	100	100	0	100	0	0	100
Split Lake - near York Landing	YL-1	# Samples	11	11	11	11	11	3	11	11	11
		# Detected	11	0	11	11	0	1	3	0	11
		% Detected	100	0	100	100	0	33	27	0	100
Split Lake	SPL-7	# Samples	19	19	19	19	19	5	19	19	19
		# Detected	19	2	19	19	0	0	6	3	19
		% Detected	100	11	100	100	0	0	32	16	100
Split Lake	SPL-8	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	4	0	4	4	0	0	2	1	0
		% Detected	100	0	100	100	0	0	50	25	0
Clark Lake	CL-1	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	4	0	4	4	0	0	2	2	4
		% Detected	100	0	100	100	0	0	50	50	100
Nelson River	NR-2	# Samples	17	17	17	17	17	4	17	17	17
		# Detected	17	2	17	17	0	1	4	2	17
		% Detected	100	12	100	100	0	25	24	12	100
Nelson River	Camp-1	# Samples	4	4	4	4	4	0	4	4	4
		# Detected	4	1	4	4	0	-	0	0	4
		% Detected	100	25	100	100	0	-	0	0	100
Nelson River	Camp-2	# Samples	4	4	4	4	4	0	4	4	4
		# Detected	4	0	4	4	0	-	0	0	4
		% Detected	100	0	100	100	0	-	0	0	100
Stephens Lake	STL-1	# Samples	20	20	20	20	20	5	20	20	20
		# Detected	20	3	19	20	0	1	7	4	20
		% Detected	100	15	95	100	0	20	35	20	100
Stephens Lake - near Gillam	GT-1	# Samples	13	13	13	13	13	4	13	13	13
		# Detected	13	1	13	13	0	1	2	1	13
		% Detected	100	8	100	100	0	25	15	8	100
Nelson River - Limestone GS Reservoir	NR-4	# Samples	15	15	15	15	15	6	15	15	15
		# Detected	15	0	15	15	0	1	2	2	15
		% Detected	100	0	100	100	0	17	13	13	100
Nelson River	NR-5	# Samples	11	11	11	11	11	4	11	11	11
		# Detected	11	0	10	11	0	0	1	1	11
		% Detected	100	0	91	100	0	0	9	9	100
Nelson River	NR-6	# Samples	12	12	12	12	12	4	12	12	12
		# Detected	12	1	11	12	0	1	1	3	12
		% Detected	100	8	92	100	0	25	8	25	100

Table 2-6: Detection frequencies exceedance for metals measured in the study area: 2001–2006

Sample Location	Location ID		Chromium (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)
Burntwood River	SPL-1	# Samples	12	12	12	12	12	12	12	12	12
		# Detected	12	12	12	12	10	12	12	0	10
		% Detected	100	100	100	100	83	100	100	0	83
Upper Nelson River	SPL-9	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	4	3	4	4	2	4	4	0	4
		% Detected	100	75	100	100	50	100	100	0	100
Upper Nelson River	SPL-2	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	3	4	4	4	1	4	4	0	4
		% Detected	75	100	100	100	25	100	100	0	100
Aiken River	AK-1	# Samples	8	8	8	8	8	8	8	8	8
		# Detected	0	4	5	8	2	8	8	0	4
		% Detected	0	50	63	100	25	100	100	0	50
Split Lake	SPL-5	# Samples	1	1	1	1	1	1	1	1	1
		# Detected	0	1	0	1	0	1	1	0	0
		% Detected	0	100	0	100	0	100	100	0	0
Split Lake - near York Landing	YL-1	# Samples	11	11	11	11	11	11	11	11	11
		# Detected	2	8	11	11	4	11	11	2	11
		% Detected	18	73	100	100	36	100	100	18	100
Split Lake	SPL-7	# Samples	19	19	19	19	19	19	19	19	19
		# Detected	12	19	18	19	17	19	19	0	19
		% Detected	63	100	95	100	89	100	100	0	100
Split Lake	SPL-8	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	3	0	3	4	3	4	4	0	4
		% Detected	75	0	75	100	75	100	100	0	100
Clark Lake	CL-1	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	4	4	3	4	2	4	4	0	4
		% Detected	100	100	75	100	50	100	100	0	100
Nelson River	NR-2	# Samples	17	17	17	17	17	17	17	17	17
		# Detected	9	17	16	17	14	17	17	0	17
		% Detected	53	100	94	100	82	100	100	0	100
Nelson River	Camp-1	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	3	4	4	4	4	4	4	1	4
		% Detected	75	100	100	100	100	100	100	25	100
Nelson River	Camp-2	# Samples	4	4	4	4	4	4	4	4	4
		# Detected	3	4	4	4	3	4	4	1	4
		% Detected	75	100	100	100	75	100	100	25	100
Stephens Lake	STL-1	# Samples	20	20	20	20	20	20	20	20	20
		# Detected	12	20	20	20	15	20	20	3	20
		% Detected	60	100	100	100	75	100	100	15	100
Stephens Lake - near Gillam	GT-1	# Samples	13	13	13	13	13	13	13	13	13
		# Detected	6	13	13	13	9	13	13	1	13
		% Detected	46	100	100	100	69	100	100	8	100
Nelson River - Limestone GS Reservoir	NR-4	# Samples	15	15	15	15	15	15	15	15	15
		# Detected	8	15	14	15	9	15	15	3	15
		% Detected	53	100	93	100	60	100	100	20	100
Nelson River	NR-5	# Samples	11	11	11	11	11	11	11	11	11
		# Detected	5	11	10	11	2	11	11	3	11
		% Detected	45	100	91	100	18	100	100	27	100
Nelson River	NR-6	# Samples	12	12	12	12	12	12	12	12	12
		# Detected	5	12	11	12	2	12	12	1	12
		% Detected	42	100	92	100	17	100	100	8	100

Table 2-6: Detection frequencies exceedance for metals measured in the study area: 2001–2006

Sample Location	Location ID		Nickel (mg/L)	Potassium (mg/L)	Selenium (mg/L)	Silver (mg/L)	Sodium (mg/L)	Strontium (mg/L)	Thallium (mg/L)	Tin (mg/L)	Uranium (mg/L)	Vanadium (mg/L)	Zinc (mg/L)
Burntwood River	SPL-1	# Samples	12	12	12	12	12	12	12	12	12	12	12
		# Detected	11	12	1	4	12	12	0	7	12	12	2
		% Detected	92	100	8	33	100	100	0	58	100	100	17
Upper Nelson River	SPL-9	# Samples	4	4	4	4	4	4	4	4	4	4	4
		# Detected	2	4	1	0	4	4	1	3	4	4	1
		% Detected	50	100	25	0	100	100	25	75	100	100	25
Upper Nelson River	SPL-2	# Samples	4	4	4	4	4	4	4	4	4	4	4
		# Detected	2	4	0	1	4	4	1	1	4	4	1
		% Detected	50	100	0	25	100	100	25	25	100	100	25
Aiken River	AK-1	# Samples	8	8	8	8	8	8	8	8	8	8	8
		# Detected	0	8	0	1	8	8	0	5	4	2	0
		% Detected	0	100	0	13	100	100	0	63	50	25	0
Split Lake	SPL-5	# Samples	1	1	1	1	1	1	1	1	1	1	1
		# Detected	0	1	0	0	1	1	0	1	1	0	0
		% Detected	0	100	0	0	100	100	0	100	100	0	0
Split Lake - near York Landing	YL-1	# Samples	11	11	11	11	11	11	11	11	11	11	11
		# Detected	4	11	1	1	11	11	1	7	11	10	1
		% Detected	36	100	9	9	100	100	9	64	100	91	9
Split Lake	SPL-7	# Samples	19	19	19	19	19	19	19	19	19	19	19
		# Detected	16	19	1	3	19	19	4	10	19	19	4
		% Detected	84	100	5	16	100	100	21	53	100	100	21
Split Lake	SPL-8	# Samples	4	4	4	4	4	4	4	4	4	4	4
		# Detected	4	4	2	0	4	4	1	0	4	4	4
		% Detected	100	100	50	0	100	100	25	0	100	100	100
Clark Lake	CL-1	# Samples	4	4	4	4	4	4	4	4	4	4	4
		# Detected	3	4	0	0	4	4	3	1	4	4	3
		% Detected	75	100	0	0	100	100	75	25	100	100	75
Nelson River	NR-2	# Samples	17	17	17	17	17	17	17	17	17	17	17
		# Detected	15	17	3	6	17	17	4	7	17	17	2
		% Detected	88	100	18	35	100	100	24	41	100	100	12
Nelson River	Camp-1	# Samples	4	4	4	4	4	4	4	4	4	4	4
		# Detected	4	4	1	3	4	4	1	4	4	4	0
		% Detected	100	100	25	75	100	100	25	100	100	100	0
Nelson River	Camp-2	# Samples	4	4	4	4	4	4	4	4	4	4	4
		# Detected	3	4	1	3	4	4	1	3	4	4	0
		% Detected	75	100	25	75	100	100	25	75	100	100	0
Stephens Lake	STL-1	# Samples	20	20	20	20	20	20	20	20	20	20	20
		# Detected	17	20	3	3	20	20	7	10	20	20	5
		% Detected	85	100	15	15	100	100	35	50	100	100	25
Stephens Lake - near Gillam	GT-1	# Samples	13	13	13	13	13	13	13	13	13	13	13
		# Detected	10	13	0	3	13	13	3	5	13	13	1
		% Detected	77	100	0	23	100	100	23	38	100	100	8
Nelson River - Limestone GS Reservoir	NR-4	# Samples	15	15	15	15	15	15	15	15	15	15	15
		# Detected	11	15	1	4	15	15	2	12	15	15	5
		% Detected	73	100	7	27	100	100	13	80	100	100	33
Nelson River	NR-5	# Samples	11	11	11	11	11	11	11	11	11	11	11
		# Detected	4	11	1	3	11	11	2	1	11	11	4
		% Detected	36	100	9	27	100	100	18	9	100	100	36
Nelson River	NR-6	# Samples	12	12	12	12	12	12	12	12	12	12	12
		# Detected	6	12	1	4	12	12	1	2	12	12	4
		% Detected	50	100	8	33	100	100	8	17	100	100	33

Table 2-7: Frequencies of exceedances of Manitoba Water Quality Standards, Objectives or Guidelines (MWQSOG) and Canadian Council of the Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) for metals and major ions measured in the study area: 2001–2006

Sample Location	Location ID		Aluminum		Arsenic		Boron		Cadmium	
			MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME
MWQSOG/CCME	**PAL**	**(mg/L)**	**0.10**	**0.10**	**0.150**	**0.005**	**1.50**	**1.50**	**0.00154–0.00335**	**0.00002–0.00005**
Aiken River	AK-1	# Samples	8	8	8	8	8	8	8	4
		# Above PAL	7	7	0	0	0	0	0	1
		% Above PAL	88	88	0	0	0	0	0	25
Burntwood River at Split Lake	SPL-1	# Samples	12	12	12	12	12	12	12	8
		# Above PAL	12	12	0	0	0	0	0	1
		% Above PAL	100	100	0	0	0	0	0	13
Upper Nelson River Upstream of Kelsey GS	SPL-9	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	4	4	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Upper Nelson River at Split Lake	SPL-2	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	4	4	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Split Lake Near York Landing	YL-1	# Samples	11	11	11	11	11	11	11	7
		# Above PAL	11	11	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Split Lake	SPL-5	# Samples	1	1	1	1	1	1	1	1
		# Above PAL	1	1	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Split Lake	SPL-7	# Samples	19	19	19	19	19	19	19	11
		# Above PAL	19	19	0	0	0	0	0	1
		% Above PAL	100	100	0	0	0	0	0	9
Split Lake	SPL-8	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	4	4	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Clark Lake	CL-1	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	4	4	0	0	0	0	0	1
		% Above PAL	100	100	0	0	0	0	0	25
Nelson River	NR-2	# Samples	17	17	17	17	17	17	17	10
		# Above PAL	17	17	0	0	0	0	0	2
		% Above PAL	100	100	0	0	0	0	0	20
Nelson River	Camp-1	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	4	4	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Nelson River	Camp-2	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	4	4	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Stephens Lake	STL-1	# Samples	20	20	20	20	20	20	20	11
		# Above PAL	20	20	0	0	0	0	0	1
		% Above PAL	100	100	0	0	0	0	0	9
Stephens Lake near Gillam	GT-1	# Samples	13	13	13	13	13	13	13	9
		# Above PAL	13	13	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Limestone Reservoir	NR-4	# Samples	15	15	15	15	15	15	15	11
		# Above PAL	15	15	0	0	0	0	0	2
		% Above PAL	100	100	0	0	0	0	0	18
Long Spruce GS Reservoir	NR-5	# Samples	11	11	11	11	11	11	11	7
		# Above PAL	11	11	0	0	0	0	0	0
		% Above PAL	100	100	0	0	0	0	0	0
Lower Nelson River	NR-6	# Samples	12	12	12	12	12	12	12	8
		# Above PAL	12	12	0	0	0	0	0	1
		% Above PAL	100	100	0	0	0	0	0	13

Table 2-7: Frequencies of exceedances of Manitoba Water Quality Standards, Objectives or Guidelines (MWQSOG) and Canadian Council of the Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) for metals and major ions measured in the study area: 2001–2006

Sample Location	Location ID		Chloride		Chromium		Copper		Iron	
			MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME
MWQSOG/CCME	**PAL**	**(mg/L)**	**-**	**120**	**0.053–0.119**	**0.0089**	**0.006–0.013**	**0.002–0.00331**	**0.30**	**0.30**
Aiken River	AK-1	# Samples	-	8	8	8	8	8	8	8
		# Above PAL	-	0	0	0	1	1	4	4
		% Above PAL	-	0	0	0	13	13	50	50
Burntwood River at Split Lake	SPL-1	# Samples	-	12	12	12	12	12	12	12
		# Above PAL	-	0	0	0	0	11	12	12
		% Above PAL	-	0	0	0	0	92	100	100
Upper Nelson River Upstream of Kelsey GS	SPL-9	# Samples	-	4	4	4	4	4	4	4
		# Above PAL	-	0	0	0	0	4	4	4
		% Above PAL	-	0	0	0	0	100	100	100
Upper Nelson River at Split Lake	SPL-2	# Samples	-	4	4	4	4	4	12	12
		# Above PAL	-	0	0	0	0	2	4	4
		% Above PAL	-	0	0	0	0	50	100	33
Split Lake Near York Landing	YL-1	# Samples	-	11	11	11	11	11	11	11
		# Above PAL	-	0	0	0	1	5	10	10
		% Above PAL	-	0	0	0	9	45	91	91
Split Lake	SPL-5	# Samples	-	1	1	1	1	1	1	1
		# Above PAL	-	0	0	0	0	0	1	1
		% Above PAL	-	0	0	0	0	0	100	100
Split Lake	SPL-7	# Samples	-	19	19	19	19	19	19	19
		# Above PAL	-	0	0	0	3	13	19	19
		% Above PAL	-	0	0	0	16	68	100	100
Split Lake	SPL-8	# Samples	-	4	4	4	4	4	4	4
		# Above PAL	-	0	0	0	0	2	4	4
		% Above PAL	-	0	0	0	0	50	100	100
Clark Lake	CL-1	# Samples	-	4	4	4	4	4	4	4
		# Above PAL	-	0	0	0	0	3	4	4
		% Above PAL	-	0	0	0	0	75	100	100
Nelson River	NR-2	# Samples	-	17	17	17	17	17	17	17
		# Above PAL	-	0	0	0	0	11	17	17
		% Above PAL	-	0	0	0	0	65	100	100
Nelson River	Camp-1	# Samples	-	4	4	4	4	4	4	4
		# Above PAL	-	0	0	0	0	4	4	4
		% Above PAL	-	0	0	0	0	100	100	100
Nelson River	Camp-2	# Samples	-	4	4	4	4	4	4	4
		# Above PAL	-	0	0	0	0	3	4	4
		% Above PAL	-	0	0	0	0	75	100	100
Stephens Lake	STL-1	# Samples	-	20	20	20	20	20	20	20
		# Above PAL	-	0	0	0	0	11	20	20
		% Above PAL	-	0	0	0	0	55	100	100
Stephens Lake near Gillam	GT-1	# Samples	-	13	13	13	13	13	13	13
		# Above PAL	-	0	0	0	0	7	13	13
		% Above PAL	-	0	0	0	0	54	100	100
Limestone Reservoir	NR-4	# Samples	-	15	15	15	15	15	15	15
		# Above PAL	-	0	0	0	1	11	15	15
		% Above PAL	-	0	0	0	7	73	100	100
Long Spruce GS Reservoir	NR-5	# Samples	-	11	11	11	11	11	11	11
		# Above PAL	-	0	0	0	0	5	10	10
		% Above PAL	-	0	0	0	0	45	91	91
Lower Nelson River	NR-6	# Samples	-	12	12	12	12	12	12	12
		# Above PAL	-	0	0	0	0	5	12	12
		% Above PAL	-	0	0	0	0	42	100	100

Table 2-7: Frequencies of exceedances of Manitoba Water Quality Standards, Objectives or Guidelines (MWQSOG) and Canadian Council of the Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) for metals and major ions measured in the study area: 2001–2006

Sample Location	Location ID		Lead		Molybdenum		Nickel		Selenium	
			MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME
MWQSOG/CCME	**PAL**	**(mg/L)**	**0.0015–0.0052**	**0.0015–0.0052**	**0.073**	**0.073**	**0.031–0.073**	**0.061–0.129**	**0.0010**	**0.0010**
Aiken River	AK-1	# Samples	8	8	8	8	8	8	8	8
		# Above PAL	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0
Burntwood River at Split Lake	SPL-1	# Samples	12	12	12	12	12	12	12	12
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	8	8
Upper Nelson River Upstream of Kelsey GS	SPL-9	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	25	25
Upper Nelson River at Split Lake	SPL-2	# Samples	12	12	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0
Split Lake Near York Landing	YL-1	# Samples	11	11	11	11	11	11	11	11
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	9	9
Split Lake	SPL-5	# Samples	1	1	1	1	1	1	1	1
		# Above PAL	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0
Split Lake	SPL-7	# Samples	19	19	19	19	19	19	19	19
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	5	5
Split Lake	SPL-8	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	2	2
		% Above PAL	0	0	0	0	0	0	50	50
Clark Lake	CL-1	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0
Nelson River	NR-2	# Samples	17	17	17	17	17	17	17	17
		# Above PAL	0	0	0	0	0	0	3	3
		% Above PAL	0	0	0	0	0	0	18	18
Nelson River	Camp-1	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	25	25
Nelson River	Camp-2	# Samples	4	4	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	25	25
Stephens Lake	STL-1	# Samples	20	20	20	20	20	20	20	20
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	5	5
Stephens Lake near Gillam	GT-1	# Samples	13	13	13	13	13	13	13	13
		# Above PAL	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0
Limestone Reservoir	NR-4	# Samples	15	15	15	15	15	15	15	15
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	7	7
Long Spruce GS Reservoir	NR-5	# Samples	11	11	11	11	11	11	11	11
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	9	9
Lower Nelson River	NR-6	# Samples	12	12	12	12	12	12	12	12
		# Above PAL	0	0	0	0	0	0	1	1
		% Above PAL	0	0	0	0	0	0	8	8

Table 2-7: Frequencies of exceedances of Manitoba Water Quality Standards, Objectives or Guidelines (MWQSOG) and Canadian Council of the Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life (PAL) for metals and major ions measured in the study area: 2001–2006

Sample Location	Location ID		Selenium		Silver		Thallium		Uranium		Zinc	
			MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME	MWQSOG	CCME
MWQSOG/CCME	**PAL**	**(mg/L)**	**0.0010**	**0.0010**	**0.0001**	**0.0001**	**0.0008**	**0.0008**	**0.015**	**0.015**	**0.07–0.17**	**0.03**
Aiken River	AK-1	# Samples	8	8	8	8	8	8	8	8	8	8
		# Above PAL	0	0	1	1	0	0	0	0	0	0
		% Above PAL	0	0	13	13	0	0	0	0	0	0
Burntwood River at Split Lake	SPL-1	# Samples	12	12	12	12	12	12	12	12	12	12
		# Above PAL	1	1	4	4	0	0	0	0	0	0
		% Above PAL	8	8	33	33	0	0	0	0	0	0
Upper Nelson River Upstream of Kelsey GS	SPL-9	# Samples	4	4	4	4	4	4	4	4	4	4
		# Above PAL	1	1	0	0	0	0	0	0	0	1
		% Above PAL	25	25	0	0	0	0	0	0	0	25
Upper Nelson River at Split Lake	SPL-2	# Samples	4	4	4	4	4	4	4	4	4	4
		# Above PAL	0	0	1	1	0	0	0	0	0	0
		% Above PAL	0	0	25	25	0	0	0	0	0	0
Split Lake Near York Landing	YL-1	# Samples	11	11	11	11	11	11	11	11	11	11
		# Above PAL	1	1	0	0	0	0	0	0	0	0
		% Above PAL	9	9	0	0	0	0	0	0	0	0
Split Lake	SPL-5	# Samples	1	1	1	1	1	1	1	1	1	1
		# Above PAL	0	0	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0	0	0
Split Lake	SPL-7	# Samples	19	19	19	19	19	19	19	19	19	19
		# Above PAL	1	1	3	3	0	0	0	0	0	0
		% Above PAL	5	5	16	16	0	0	0	0	0	0
Split Lake	SPL-8	# Samples	4	4	4	4	4	4	4	4	4	4
		# Above PAL	2	2	0	0	0	0	0	0	0	1
		% Above PAL	50	50	0	0	0	0	0	0	0	25
Clark Lake	CL-1	# Samples	4	4	4	4	4	4	4	4	4	4
		# Above PAL	0	0	0	0	0	0	0	0	0	0
		% Above PAL	0	0	0	0	0	0	0	0	0	0
Nelson River	NR-2	# Samples	17	17	17	17	17	17	17	17	17	17
		# Above PAL	3	3	6	6	0	0	0	0	0	1
		% Above PAL	18	18	35	35	0	0	0	0	0	6
Nelson River	Camp-1	# Samples	4	4	4	4	4	4	4	4	4	4
		# Above PAL	1	1	3	3	0	0	0	0	0	0
		% Above PAL	25	25	75	75	0	0	0	0	0	0
Nelson River	Camp-2	# Samples	4	4	4	4	4	4	4	4	4	4
		# Above PAL	1	1	3	3	0	0	0	0	0	0
		% Above PAL	25	25	75	75	0	0	0	0	0	0
Stephens Lake	STL-1	# Samples	20	20	20	20	20	20	20	20	20	20
		# Above PAL	1	1	0	0	0	0	0	0	0	0
		% Above PAL	5	5	0	0	0	0	0	0	0	0
Stephens Lake near Gillam	GT-1	# Samples	13	13	13	13	13	13	13	13	13	13
		# Above PAL	0	0	2	2	0	0	0	0	0	0
		% Above PAL	0	0	15	15	0	0	0	0	0	0
Limestone Reservoir	NR-4	# Samples	15	15	15	15	15	15	15	15	15	15
		# Above PAL	1	1	4	4	0	0	0	0	0	1
		% Above PAL	7	7	27	27	0	0	0	0	0	7
Long Spruce GS Reservoir	NR-5	# Samples	11	11	11	11	11	11	11	11	11	11
		# Above PAL	1	1	3	3	0	0	0	0	0	2
		% Above PAL	9	9	27	27	0	0	0	0	0	18
Lower Nelson River	NR-6	# Samples	12	12	12	12	12	12	12	12	12	12
		# Above PAL	1	1	4	4	0	0	0	0	0	2
		% Above PAL	8	8	33	33	0	0	0	0	0	17

Table 2-8: Range of metals and major ions in surface waters in major regions of Canada, as reported in Canadian Council of Resource and Environment Ministers (1987). All units in mg/L

Parameter	Region of Canada				Comments
	Pacific	Western	Central	Atlantic	
Aluminum	-	-	-	-	Range across Canada: <0.02–70 mg/L
Barium	<0.1	<0.0001–2.2	0.05–0.07	<0.02–1.0	-
Beryllium	-	-	-	-	Average Surface Waters: <0.001 mg/L
Boron	<0.01–2.00	0.01–0.059	<0.01–3.69	<0.01–2.30	Median MB concentration: 0.15 mg/L
Cadmium	<0.01	-	<0.01	-	-
Calcium	1.19–62.3	<0.5–474	<0.002–349	0.4–260	Typically <15 mg/L; waters close to carbonate rocks range from 30-100 mg/L
Dissolved Chloride	<0.1–27.0	0.1–473.0	<0.1–450.0	0.04–861.0	Typically <10 mg/L in humid regions
Chromium	-	-	0.002–0.044	0.001–0.024	-
Cobalt	<0.001	<0.001–0.047	-	<0.001	-
Copper	0.001–0.080	0.007–0.071	0.001–0.068	0.002–0.070	Typically <0.020 mg/L in surface waters
Fluoride	<0.02–2.60	<0.02–0.74	0.0–2.0	<0.02–0.29	Typically <1 mg/L in surface waters.
Iron	<0.001–54.0	0.04–11.0 [1]	0.001–7.55	0.004–3.1	Typically <0.5 mg/L in aerated surface waters.
Lead	0.001–0.004	0.001–0.077 [2]	0.001–0.046	0.001–0.041	-
Magnesium	14.0–18.0 [3]	44–181	<0.05–1000	<0.05–954.0	-
Manganese	0.01–1.70	0.01–4.8 [1]	0.001–0.26	0.002–0.737	Typically <0.2 mg/L; may be >0.2 mg/L in deep stratified lakes and reservoirs under reducing conditions. Typically in suspended form.
Mercury	<0.00005	<0.00002–0.00024	0.000005–0.0001	-	-
Molybdenum	-	-	-	-	Typically <1 mg/L in freshwater
Nickel	<0.001–0.003	0.001–0.280	0.001–0.025	0.001–0.003	-

Table 2-8: Range of metals and major ions in surface waters in major regions of Canada, as reported in Canadian Council of Resource and Environment Ministers (1987). All units in mg/L

Parameter	Region of Canada				Comments
	Pacific	Western	Central	Atlantic	
Potassium	<0.1–9.3 [3]	0.03–33.0 [3]	<0.1–7 [3]	0.26–1.52	Typically <10 mg/L
Selenium	0.0001–0.0002	-	0.0001–0.004	<0.0005–0.001	-
Silver	<0.005–0.010	<0.005–<0.01	-	<0.005–<0.01	-
Sodium	-	-	-	-	Varies widely from <1 mg/L to 1,000,000 mg/L
Sulphate	<1.0–820.0	<1.0–3040.0	<1.0–77.3	<1.0–610.0	Typically varies from 10 to 80 mg/L
Thallium	0.0052–0.1 [4]	-	-		-
Tin	-	-	-	-	Typically range from 0.001–0.002 mg/L when detected
Titanium	-	-	-	-	Range of 0.002–0.107 mg/L across Canada and US
Uranium	0.0001–0.0021	0.000097–0.00214 [4]	0.00028–0.00065 [5]	0.00025–0.00073	-
Vanadium	-	<0.0005–0.11	-	-	Range from 0.0003–0.2 mg/L in fresh water
Zinc	0.001–0.130	0.001–0.290	0.001–1.170	0.0001–0.190	-

1. Extractable.
2. Recoverable.
3. Dissolved.
4. Only three samples taken.
5. Only Ontario data.

Table 2-9: Range of routine water quality variables in surface waters in major regions of Canada, as reported in Canadian Council of Resource and Environment Ministers (1987)

Parameter[1]	Units	Region				
		Pacific	Western	Central	Atlantic	Comments
Alkalinity (total) - as $CaCO_3$	mg/L	0.5–162	1.0–750	<0.5–210.9	<0.5–440	Typically <500
pH		-	4.1–10.2	2.8–9.6	2.8–9.2	
Hardness (as $CaCO_3$)	mg/L	12.6–236.0	-	2.1–280.2	3.0–28.2	
TKN	mg/L	0.014–20.0	0.148–2.63	0.004–31.7	0.001–2.542	
Ammonia	mg/L	<0.001–0.49	0.014–2.00	0.008–0.587	0.002–0.104	Typically <0.1 mg/L N
	mg N/L					
Nitrate/nitrite	mg N/L	<0.002–3.60	<0.001–190.0	<0.001–10.6	<0.001–18.571	
Dissolved Oxygen	mg/L	0.1–16.2	<0.01–18.4	<0.01–17.55	2.2–16.8	
	% Saturation			3–140	1–124	Typically <10 mg/L
TP	mg/L	0.0013–1.76	0.003–3.0	<0.002–12.84	0.001–4.3	
TOC	mg/L	0.01–0.26	<0.5–1610	0.4–27	0.01–183	
Colour	TCU	<5–40	5–240	5–200	65–130	
Specific Conductance	µS/cm	4.8–84600	-	0.003–2000	0.008–31000	
TDS	mg/L		4–65879			Most lakes with open basins typically have TDS of approximately 100–200 mg/L
Filterable residues	mg/L	<2–990	0.002–5873	0.2–23536	1–3284	

1. TKN = total Kjeldahl nitrogen, TP = total phosphorus, TOC = total organic carbon, TDS = total dissolved solids

Table 2-10: Statistical summaries of total aluminum and iron measured in the open water season (May-October) from 1997–2006 in the Red and Assiniboine rivers. Data were provided by Manitoba Water Stewardship (MWS 2009)

	Total Aluminum (mg/L)			Total Iron (mg/L)		
	Red River at Floodway	Red River at Selkirk	Assiniboine River at Headingley	Red River at Floodway	Red River at Selkirk	Assiniboine River at Headingley
Mean	2.38	2.65	2.48	3.63	2.82	3.53
Minimum	0.20	0.17	0.12	0.24	0.28	0.43
Maximum	11.4	30	8.2	18.0	14.9	10.7
n[1]	17	56	17	20	63	61
SE[2]	0.68	0.62	0.55	0.94	0.36	0.26

1. Number of samples.
2. Standard error.

Table 2-11: Construction-related activities, potential effects to water quality, and proposed mitigation measures

Action/Activity	First Order Effect/Pathway	Mitigation Measures
Generating Station		
Placement of excavated materials in the future reservoir.	Release of sediments when material is flooded during impoundment.	Capping with erosion-resistant material where water velocity expected to be sufficient to suspend waste material in water column.
Placement and removal of cofferdams	Introduction of fine suspended materials (river bottom sediments and cofferdam material) to surface water during construction and removal of dams. Inputs of substances during dewatering.	Design of cofferdam cross sections and construction methods to minimize losses of fine material; riprap to reduce erosion from cofferdam surface; seepage and other water collected behind cofferdam after initial dewatering will be tested and treated, if required, prior to release to surface waters. See text and the Keeyask GS EnvPP for additional details.
Diversion, impoundment and initial operation.	Release of suspended sediments, including erosion of riverbanks and riverbeds.	None.
Runoff from the access roads, camp site, work areas and other cleared lands (*e.g.*, borrow sites), including potential inputs via groundwater.	Inputs of sediments and potentially other contaminants (*e.g.*, metals, hydrocarbons) from runoff from parking lots, work areas, material stockpiles, and other sites.	Drainage plans will be developed to manage drainage from areas such as material stockpiles. Drainage waters will be monitored to ensure adequate quality prior to entering natural waterways. Buffer zones adjacent to water courses. Various erosion and sediment control measures will be implemented as described in the Keeyask GS EnvPP and the Keeyask South Access Road EnvPP.
Water treatment plant	Discharge of treatment plant backwash.	Water treatment plant backwash will be treated if required, such that total suspended solids (TSS) will be < 25 mg/L prior to discharge to the receiving environment.
Release of treated sewage effluent	Inputs of BOD, pH, TSS/turbidity, nutrients, ammonia, metals, organic carbon, colour, (residual chlorines will not be discharged) to surface waters.	Sewage from the construction camp will be treated in a wastewater treatment facility and tested as required prior to release to surface waters. Effluent will meet the requirements identified in the *Manitoba Environment Act* Licence (Licence No. 2952).

Table 2-11: Construction-related activities, potential effects to water quality, and proposed mitigation measures

Action/Activity	First Order Effect/Pathway	Mitigation Measures
Release of wash water from aggregate washing and concrete processing to surface water environment.	Waters may contain suspended sediments and affect parameters such as pH.	Wash water and concrete batch plant effluent will be treated and will not be released until TSS is <25 mg/L. Concrete batch plant effluent will be treated if required to maintain pH within PAL guidelines.
Blasting.	Release of particulates (*i.e.*, TSS) and ammonia/nitrate to surface waters.	It is anticipated that blasting will be conducted in-the-dry and activities will adhere to guidelines developed by Fisheries and Oceans Canada. ANFOs will not be used in areas that will come into contact with surface waters.
Placement of excavated rock materials on cofferdams, main dam, and other structures.	Acid leachate generation from rock surfaces exposed to air potentially introducing metals and lowering pH in the aquatic environment.	Addressed through testing of materials and application of mitigation if required.
Construction of powerhouse, dykes, main dam and other structures.	Release of substances associated with construction (*e.g.*, sediments) to surface waters.	Construction carried out in-the-dry (*e.g.*, behind cofferdams or on land) minimizing potential for inputs to surface waters. Surfaces protected from erosion (*e.g.*, rockfill) where required.
Placement of concrete in surface waters.	Contact of surface water with newly formed concrete structures can affect pH.	Concrete will not be poured in-the-wet.
Accidental spills and releases of hazardous substances.	Direct or indirect introduction of contaminants to surface waters.	Transportation, storage, and handling of dangerous goods by established policies and regulations. Spill response programs and equipment will be in place. See Keeyask GS EnvPP for additional information.
South Access Road		
Clearing of Right-of-Way	Inputs of sediments due to increased erosion as a result of the removal of the protective layer of vegetation.	Minimize clearing, hand clearing in sensitive areas, grubbing only where required (*e.g.*, road embankment and ditch). Use of standard sediment and erosion control measures (see Keeyask South Access Road EnvPP for additional details).

Table 2-11: Construction-related activities, potential effects to water quality, and proposed mitigation measures

Action/Activity	First Order Effect/Pathway	Mitigation Measures
Construction of road	Release of sediments from road, ditches and slopes of borrow areas.	Appropriately sloped banks; implementation of various erosion and sediment control measures (*e.g.*, use of straw bales and silt fences, promotion of revegetation, buffer zones adjacent to water courses).
Installation of stream crossings	Release of sediments due to in-stream excavation, inputs from materials used for fill, and erosion from adjacent streambed and banks.	Crossings constructed during winter if possible when flow minimal, isolation of work areas, use of clean fill for crossings, riprap on stream banks and beds adjacent to culvert, culverts sized and positioned appropriately to pass flow.

Table 2-12. Effects of the Keeyask Generating Station on water quality: construction period. Effects that begin during construction and continue to operation are addressed under operation

Linkage/Pathway	Mitigation/Enhancement	Effect
Keeyask Area/Stephens Lake Area		
Increases in concentrations of total suspended solids (TSS), nutrients, metals, bacteria and levels of pH and decreases in dissolved oxygen (DO) could arise due to: ▪ Discharge of sewage effluent, wastewaters from processing of aggregate materials and concrete, dewatering of cofferdams, *etc.*; ▪ Diversion and impoundment during river management resulting in water level/flow changes and changes in the ice regime and shoreline erosion; ▪ Runoff from the camp site, work areas, reservoir clearing area and other cleared lands, including potential inputs via groundwater; ▪ Construction of instream structures, including placement and removal of cofferdams, excavated materials disposal *etc.*; ▪ Leachate from waste rock stockpiles and structures containing rock exposed to surface waters/drainage; ▪ Blasting; and ▪ Accidental spills/releases.	Mitigation includes: Sewage effluent will be treated to meet will meet or exceed the specifications identified in Manitoba Environment Act Licence (Licence No. 2952); Wash water from the concrete aggregate and batch plant will be treated through a two-cell settling pond and effluent will not be released until TSS concentrations are < 25 mg/L. Effluent will also be treated for pH prior to release if required. Excavated materials disposed of in the reservoir will be covered with appropriate materials to prevent introduction of solids (TSS); Effects related to site drainage and runoff on surface water quality will be minimized through implementation of sediment and erosion control measures; Water that is trapped behind cofferdams will be treated to reduce TSS concentrations (*i.e.*, through settling) to <25 mg/L if required prior to release to surface waters. It is anticipated that all blasting activities will occur in-the-dry and in accordance with DFO Blasting Guidelines. ANFOs will not be used in areas that will come into contact with surface waters. Rock that could potentially be used to construct the Project was tested for the potential to generate acid leachate. Additional testing of materials will be conducted during construction as required. Best Management Practices to prevent the introduction of hazardous substances to the aquatic environment. Sediment management measures for instream construction as outlined in the Sediment Management Plan and the EnvPP.	**TSS** Effects on TSS during construction will be largely related to water diversion and impoundment and cofferdam/groin placement and removal. Effects are expected to range from small to moderate in the fully mixed Nelson River. TSS concentrations may be higher in the immediate vicinity of sediment inputs. **Nutrients, DO, and pH** Effects on nutrients, DO, and pH would be primarily related to the effects of river diversion and impoundment (*i.e.*, flooding) which are discussed under the effects assessment for the Project Operation period. Effects related to other pathways are expected to be negligible to small due to mitigation measures. **Metals and Hydrocarbons** Effects are expected to be negligible due to mitigation measures.

Table 2-12. Effects of the Keeyask Generating Station on water quality: construction period. Effects that begin during construction and continue to operation are addressed under operation

Linkage/Pathway	Mitigation/Enhancement	Effect
Downstream Area Effects of Project construction on water quality downstream of Stephens Lake are related to effects on water quality upstream of the Kettle GS.	See mitigation identified above (*i.e.*, measures to minimize TSS).	**TSS** Small increases in TSS are expected in the Lower Nelson River downstream of Stephens Lake during certain construction periods.
South Access Road Construction of the south access road (*i.e.*, installation of three culverts and clearing the RoW) may introduce sediments to the natural watercourses through erosion and/or resuspension of sediments.	Mitigation would include procedures described in the "Manitoba Stream Crossing Guidelines for the Protection of Fish and Fish Habitat" and the Keeyask South Access Road EnvPP.	None

Table 2-13: Dissolved oxygen concentrations at the upstream end of the model area ("upstream") and near the generating station ("reservoir"). Information regarding the DO model and results is presented in the Physical Environment Supporting Volume, Section 9

Scenario Description	Modelling Period	Description	Year of Operation	Location	Dissolved oxygen (mg/L)		
					Surface	Mid-depth	Bottom
Base Loaded Mode – Typical Week	Summer	steady wind and typical weather, median flows, base loaded	1	Upstream	8.56	8.53	8.52
				Reservoir	8.66	8.62	8.60
Base Loaded Mode – Critical Week	Summer	variable wind, more extreme weather, median flows, base loaded	1	Upstream	8.49	8.52	8.48
				Reservoir	8.14	8.13	8.11
Peaking Mode – Critical Week	Summer	same as 8 but dynamic flows (peaking mode)	1	Upstream	8.54	8.52	8.51
				Reservoir	8.52	8.49	8.48
Base Loaded Mode	Winter	median flows, base loaded scenario 1	1	Upstream	14.59	14.59	14.59
				Reservoir	14.36	14.36	14.35
Peaking Mode	Winter	median flows, dynamic peaking mode flows 1	1	Upstream	14.60	14.59	14.59
				Reservoir	14.44	14.44	14.44
Base Loaded Mode	Summer	variable wind, more extreme weather, median flows, base loaded	5	Upstream	8.49	8.49	8.49
				Reservoir	8.16	8.13	8.09

Table 2-14: Areas of the Keeyask reservoir within defined ranges of dissolved oxygen: summer, Year 1 of operation. Areas were derived from dissolved oxygen (DO) model as described in the Physical Environment Supporting Volume, Section 9

Category	Base Loaded Mode – Typical Week	Base Loaded Mode – Critical Week	Peaking Mode – Critical Week
Surface Layer			
Total Reservoir Area	93.2	93.2	93.2
Total Reservoir Area Modelled	91.1	91.2	87.6
Undefined Area	2.1	2.1	5.7
Area with DO = 0–2 mg/L	0.0	0.0	0.0
Area with DO = 2–4 mg/L	0.0	0.2	0.0
Area with DO = 4–6.5 mg/L	0.0	17.5	2.1
Area with DO >6.5 mg/L	91.1	73.5	85.5
Total	93.2	93.2	93.2
Mid-Depth Layer			
Total Reservoir Area	93.2	93.2	93.2
Total Reservoir Area Modelled	91.1	91.2	87.6
Undefined Area	2.1	2.1	5.7
Area with DO = 0–2 mg/L	0.0	0.0	0.0
Area with DO = 2–4 mg/L	0.0	1.1	0.2
Area with DO = 4–6.5 mg/L	0.0	18.3	5.0
Area with DO >6.5 mg/L	91.1	71.8	82.4
Total	93.2	93.2	93.2
Bottom Layer			
Total Reservoir Area	93.2	93.2	93.2
Total Reservoir Area Modelled	91.1	91.2	87.6
Undefined Area	2.1	2.1	5.7
Area with DO = 0–2 mg/L	0.0	0.3	1.3
Area with DO = 2–4 mg/L	0.0	3.7	3.2
Area with DO = 4–6.5 mg/L	0.0	16.8	9.4
Area with DO >6.5 mg/L	91.1	70.4	73.7
Total	93.2	93.2	93.2

Table 2-15: Areas of the Keeyask reservoir within defined ranges of dissolved oxygen: winter, Year 1 of operation. Areas were derived from dissolved oxygen (DO) model as described in the Physical Environment Supporting Volume, Section 9

Category	Base Loaded Mode	Peaking Mode
Surface Layer		
Total Reservoir Area	93.2	93.2
Total Reservoir Area Modelled	81.4	74.7
Undefined Area	11.8	18.5
Area with DO = 0–2 mg/L	1.5	2.1
Area with DO = 2–3 mg/L	0.6	0.6
Area with DO = 3–4 mg/L	0.7	0.9
Area with DO = 4–5.5 mg/L	1.6	0.9
Area with DO = 5.5–8 mg/L	3.0	2.5
Area with DO = 8–9.5 mg/L	1.7	1.9
Area with DO >9.5 mg/L	72.4	65.8
Total	93.2	93.2
Mid-Depth Layer		
Total Reservoir Area	93.2	93.2
Total Reservoir Area Modelled	81.4	74.7
Undefined Area	11.9	18.6
Area with DO = 0–2 mg/L	2.6	2.8
Area with DO = 2–3 mg/L	1.3	0.8
Area with DO = 3–4 mg/L	0.9	1.7
Area with DO = 4–5.5 mg/L	1.5	1.6
Area with DO = 5.5–8 mg/L	3.2	2.3
Area with DO = 8–9.5 mg/L	1.7	2.4
Area with DO >9.5 mg/L	70.1	63.1
Total	93.2	93.2
Bottom Layer		
Total Reservoir Area	93.2	93.2
Total Reservoir Area Modelled	81.3	74.6
Undefined Area	11.9	18.7
Area with DO = 0–2 mg/L	5.1	5.7
Area with DO = 2–3 mg/L	1.0	1.2

Table 2-15: Areas of the Keeyask reservoir within defined ranges of dissolved oxygen: winter, Year 1 of operation. Areas were derived from dissolved oxygen (DO) model as described in the Physical Environment Supporting Volume, Section 9

Category	Base Loaded Mode	Peaking Mode
Area with DO = 3–4 mg/L	1.1	1.0
Area with DO = 4–5.5 mg/L	1.6	1.1
Area with DO = 5.5–8 mg/L	2.2	2.6
Area with DO = 8–9.5 mg/L	1.2	1.3
Area with DO >9.5 mg/L	69.0	61.6
Total	**93.2**	**93.2**

Table 2-16: Areas of the Keeyask reservoir within defined ranges of dissolved oxygen: summer, Year 5 of operation and Year 1 for comparison (Base Loaded Mode – Critical Week). Areas were derived from dissolved oxygen (DO) model as described in the Physical Environment Supporting Volume, Section 9

Category	Year 1	Year 5
Surface Layer		
Total Reservoir Area	93.2	95.0
Total Reservoir Area Modelled	91.2	94.9
Undefined Area	2.1	0.1
Area with DO = 0–2 mg/L	0.0	0.0
Area with DO = 2–4 mg/L	0.2	0.0
Area with DO = 4–6.5 mg/L	17.5	16.8
Area with DO >6.5 mg/L	73.5	78.1
Total	93.2	95.0
Mid-Depth Layer		
Total Reservoir Area	93.2	95.0
Total Reservoir Area Modelled	91.2	94.9
Undefined Area	2.1	0.1
Area with DO = 0–2 mg/L	0.0	0.0
Area with DO = 2–4 mg/L	1.1	1.4
Area with DO = 4–6.5 mg/L	18.3	17.2
Area with DO >6.5 mg/L	71.8	76.3
Total	93.2	95.0
Bottom Layer		
Total Reservoir Area	93.2	95.0
Total Reservoir Area Modelled	91.2	94.9
Undefined Area	2.1	0.1
Area with DO = 0–2 mg/L	0.3	1.2
Area with DO = 2–4 mg/L	3.7	4.1
Area with DO = 4–6.5 mg/L	16.8	15.2
Area with DO >6.5 mg/L	70.4	74.3
Total	93.2	95.0

Table 2-17: Dose response database of early life stages of salmonids exposed to acute and chronic concentrations of suspended solids (from Newcombe and Jensen 1996)

Species	Life stage	Exposure concentration (mg/L)	Exposure Duration (h)	Fish response	Reference
Trout	eggs	117	960	egg mortality; deterioration of spawning gravel beds	Cederholm *et al.* (1981)
Trout (rainbow)	egg	20.8	1,152	Mortality rate 72%	Slaney *et al.* (1977a)
Trout (rainbow)	egg	6.6	1,152	Mortality 40%	Slaney *et al.* (1977b)
Trout (rainbow)	egg	37	1,488	hatching success 42% (controls 63%)	Slaney *et al.* (1977b)
Trout (rainbow)	egg	46.6	1,152	100% mortality	Slaney *et al.* (1977b)
Trout (rainbow)	egg	57	1,488	Mortality of eggs 47% (controls 32%)	Slaney *et al.* (1977b)
Trout (rainbow)	egg	120	384	Mortality ~ 60-70% (controls 38.6%)	Erman and Lignon (1988)
Trout (rainbow)	egg	101	1,440	98% mortality (controls 14.6%)	Turnpenny and Williams (1980)
Trout (rainbow)	eyed egg	1,750	144	increased mortality rate (control 6%)	Campbell (1954)
Grayling (Arctic)	sac fry	25	24	Mortality rate of 5.7%	LaPerriere (*pers. comm.*)
Grayling (Arctic)	sac fry	22.5	48	Mortality rate of 14.0%	LaPerriere (*pers. comm.*)
Grayling (Arctic)	sac fry	65	24	Mortality rate of 15.0%	LaPerriere (*pers. comm.*)
Grayling (Arctic)	sac fry	21.7	72	Mortality rate of 14.7%	LaPerriere (*pers. comm.*)
Grayling (Arctic)	sac fry	20	96	Mortality rate of 13.4%	LaPerriere (*pers. comm.*)
Grayling (Arctic)	sac fry	142.5	48	Mortality rate of 26%	LaPerriere (*pers. comm.*)

Table 2-17: Dose response database of early life stages of salmonids exposed to acute and chronic concentrations of suspended solids (from Newcombe and Jensen 1996)

Species	Life stage	Exposure concentration (mg/L)	Exposure Duration (h)	Fish response	Reference
Grayling (Arctic)	sac fry	185	72	Mortality rate of 41.3%	LaPerriere (*pers. comm.*)
Grayling (Arctic)	sac fry	230	96	Mortality rate of 47%	LaPerriere (*pers. comm.*)
Salmon	eggs	117	960	egg mortality; deterioration of spawning gravel beds	Cederholm *et al.* (1981)
Salmon (Coho)	egg	157	1,728	100% mortality (controls 16.2%)	Shaw and Maga (1943)
Salmon (chum)	egg	97	2,808	77% mortality rate (controls 6%)	Lagner (1980)
Trout (steelhead)	egg	37	1,488	42% hatching success (controls 63%)	Slaney *et al.* (1977b)

Table 2-18: Summary of model predictions for total phosphorus (TP) related to organic total suspended solids (TSS) and decomposition of flooded organic materials

Peat Zone	TP (mg/L)					
	Increase from Organic TSS Pathway[1]	Increase from Flooding/Decomposition Pathway [1]	Combined Increase in TP	Background TP	Background with Increased TP	% Increase Above Background
1	0.0005	0.0009	0.0014	0.039	0.040	3.5
2	0.0009	0.0010	0.0019	0.039	0.041	4.9
3	0.0005	0.0005	0.0009	0.039	0.040	2.4
4 [2]	Not Modelled	0.041	0.0409	0.039	0.080	104.8
5	0.0009	0.016	0.0170	0.039	0.056	43.5
7	0.0046	0.014	0.0190	0.039	0.058	48.7
8	0.0096	0.021	0.0302	0.039	0.069	77.4
9	0.0036	0.019	0.0224	0.039	0.061	57.4
10	0.0018	0.015	0.0172	0.039	0.056	44.1
11	0.0068	0.017	0.0234	0.039	0.062	59.9
12	0.0041	0.014	0.0185	0.039	0.058	47.5
13	0.0014	0.016	0.0169	0.039	0.056	43.3

1. Mid-range of estimates presented in Appendix 2F.
2. Totals reflect the effects of the flooding pathway only. Effects to organic TSS were not modelled for this peat transport zone.

Table 2-19: Summary of model predictions for total nitrogen (TN) related to organic total suspended solids (TSS) and decomposition of flooded organic materials

Peat Zone	TN (mg/L)					
	Increase from Organic TSS Pathway	Increase From Flooding/Decomposition Pathway [1]	Combined Increase in TN	Background TN	Background with Increased TN	% Increase Above Background
1	0.013	0.02	0.03	0.5	0.53	7
2	0.027	0.02	0.05	0.5	0.55	10
3	0.013	0.01	0.02	0.5	0.52	5
4 [2]	Not Modelled	0.9	0.92 [2]	0.5	1.42 [2]	184 [2]
5	0.027	0.4	0.39	0.5	0.89	78
7	0.134	0.3	0.46	0.5	0.96	92
8	0.282	0.5	0.75	0.5	1.25	149
9	0.107	0.4	0.53	0.5	1.03	106
10	0.054	0.3	0.40	0.5	0.90	80
11	0.201	0.4	0.57	0.5	1.07	115
12	0.121	0.3	0.45	0.5	0.95	89
13	0.040	0.3	0.39	0.5	0.89	78

1. Mid-range of estimates presented in Appendix 2F.
2. Totals reflect the effects of the flooding pathway only. Effects to organic TSS were not modelled for this peat transport zone.

Table 2-20: Summary of estimated changes in concentrations of metals associated with organic total suspended solids (TSS) and flooding and comparison to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) and Canadian Council of Ministers of the Environment (CCME) guidelines for the protection of aquatic life (PAL) and drinking water (DW). Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001–2004. Values in red indicate measurements that exceeded the associated guidelines indicated in red

Peat Transport Zone		Estimated metal concentrations (mg/L)																	
		Aluminum		**Antimony**		**Arsenic**		**Barium**		**Cadmium**		**Chromium**		**Copper**		**Iron**		**Lead**	
		Mean BG	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**
Background Concentration		1.50	2.53	<0.001	<0.001	0.0013	0.0025	0.0389	0.0456	0.00002	0.00009	<0.002	0.003	0.003	0.007	1.12	1.66	0.0007	0.0014
1		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.000021	0.000091	<0.002	0.003	0.0030	0.0070	1.13	1.67	0.0007	0.0014
2		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0391	0.0458	0.000021	0.000091	<0.002	0.003	0.0030	0.0070	1.13	1.67	0.0007	0.0014
3		1.51	2.54	<0.001	<0.001	0.0013	0.0025	0.0390	0.0457	0.000021	0.000091	<0.002	0.003	0.0030	0.0070	1.12	1.66	0.0007	0.0014
4		1.77	2.80	<0.001	<0.001	0.0015	0.0027	0.0433	0.0500	0.000050	0.000120	<0.002	0.003	0.0035	0.0075	1.31	1.85	0.0010	0.0017
5		1.61	2.64	<0.001	<0.001	0.0014	0.0026	0.0407	0.0474	0.000032	0.000102	<0.002	0.003	0.0032	0.0072	1.20	1.74	0.0008	0.0015
7		1.62	2.65	<0.001	<0.001	0.0014	0.0026	0.0409	0.0476	0.000034	0.000104	<0.002	0.003	0.0032	0.0072	1.21	1.75	0.0008	0.0015
8		1.70	2.73	<0.001	<0.001	0.0014	0.0026	0.0421	0.0488	0.000042	0.000112	<0.002	0.003	0.0034	0.0074	1.26	1.80	0.0009	0.0016
9		1.65	2.68	<0.001	<0.001	0.0014	0.0026	0.0413	0.0480	0.000036	0.000106	<0.002	0.003	0.0033	0.0073	1.22	1.76	0.0009	0.0016
10		1.61	2.64	<0.001	<0.001	0.0014	0.0026	0.0407	0.0474	0.000032	0.000102	<0.002	0.003	0.0032	0.0072	1.20	1.74	0.0008	0.0015
11		1.65	2.68	<0.001	<0.001	0.0014	0.0026	0.0414	0.0481	0.000037	0.000107	<0.002	0.003	0.0033	0.0073	1.23	1.77	0.0009	0.0016
12		1.62	2.65	<0.001	<0.001	0.0014	0.0026	0.0409	0.0476	0.000033	0.000103	<0.002	0.003	0.0032	0.0072	1.21	1.75	0.0008	0.0015
13		1.61	2.64	<0.001	<0.001	0.0014	0.0026	0.0407	0.0474	0.000032	0.000102	<0.002	0.003	0.0032	0.0072	1.20	1.74	0.0008	0.0015
MWQSOG PAL		0.100		-		-		-		-		-		-		0.300		-	
	PAL - 4-day	-		-		0.150		-		0.0027	0.0031	0.094	0.110	0.010	0.012	-		0.004	0.005
	PAL - 1-hour	-		-		0.340		-		0.0051	0.0063	1.964	2.291	0.015	0.018	-		0.093	0.119
CCME PAL		0.100		-		0.005		-		0.000037	0.000043	0.0089		0.0026	0.003	0.300		0.0037	0.0046
MWQSOGs and CCME DW	MAC	-		0.006		0.010		1.000		0.005		0.050		-		-		0.010	
	AO	-		-		-		-		-		-		1.000		0.300		-	

Table 2-20: Summary of estimated changes in concentrations of metals associated with organic total suspended solids (TSS) and flooding and comparison to Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) and Canadian Council of Ministers of the Environment (CCME) guidelines for the protection of aquatic life (PAL) and drinking water (DW). Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001–2004. Values in red indicate measurements that exceeded the associated guidelines indicated in red

Peat Transport Zone		Estimated metal concentrations (mg/L)																	
		Manganese		Mercury [1]	Mercury [2]	Molybdenum		Nickel		Selenium		Silver		Sodium		Uranium		Zinc	
		Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG	Mean BG	Max BG
Background Concentration		0.0231	0.0314	0.00000088	0.00000050	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
1		0.0234	0.0317	0.0000014	0.0000010	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
2		0.0236	0.0319	0.0000015	0.0000011	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
3		0.0233	0.0316	0.0000013	0.0000009	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.43	18.10	0.0005	0.0007	<0.02	0.07
4		0.0333	0.0416	0.0000113	0.0000109	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.48	18.15	0.0014	0.0016	<0.02	0.07
5		0.0273	0.0356	0.0000059	0.0000055	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07
7		0.0278	0.0361	0.0000128	0.0000124	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07
8		0.0305	0.0388	0.0000159	0.0000155	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.46	18.13	0.0011	0.0013	<0.02	0.07
9		0.0286	0.0369	0.0000119	0.0000115	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.46	18.13	0.0010	0.0012	<0.02	0.07
10		0.0274	0.0357	0.0000077	0.0000073	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07
11		0.0289	0.0372	0.0000130	0.0000126	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.46	18.13	0.0010	0.0012	<0.02	0.07
12		0.0277	0.0360	0.0000069	0.0000065	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07
13		0.0273	0.0356	0.0000060	0.0000057	0.0006	0.0008	0.003	0.004	<0.001	0.001	0.0001	0.0007	13.45	18.12	0.0009	0.0011	<0.02	0.07
MWQSOG PAL		-		0.000026 (inorganic); 0.000004 (methylmercury)		0.073		-		0.001		0.0001		-		0.015 2		-	
	PAL - 4-day	-		-		-		0.057	0.067	-		-		-		-		0.13	0.15
	PAL - 1-hour	-		-		-		0.512	0.601	-		-		-		-		0.13	0.15
CCME PAL		-		0.000026 (inorganic); 0.000004 (methylmercury)		0.073		0.104	0.119	0.001		0.0001		-		0.015 2		0.03	
MWQSOGs/CCME DW	MAC	-		0.001		-		-		0.010		-		-		0.020		-	
	AO	0.050		-		-		-		-		-		200		-		5	

MAC = maximum acceptable concentration; and AO = aesthetic objective.
1. Mean value presented in Kirk and St. Louis (2009) for the Limestone GS.
2. Mean value for samples collected from the Aquatic Environment Study Area in fall 2011.

Table 2-21: Summary of estimated changes in concentrations of metals for which there are no Manitoba water quality guidelines, associated with organic total suspended solids and flooding. Values represent the estimated concentrations under mean and maximum (Max) background (BG) concentrations of metals measured in the Nelson River near Gull Lake in the open water seasons of 2001–2004

Peat Transport Zone	Concentration (mg/L)																	
	Beryllium		**Bismuth**		**Calcium**		**Cobalt**		**Magnesium**		**Potassium**		**Strontium**		**Tin**		**Vanadium**	
	Mean BG	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**	**Mean BG**	**Max BG**
Background Concentration	<0.001	<0.001	<0.0001	0.0001	27.4	32.4	0.0006	0.0013	10.28	12.57	2.7	3.1	0.0924	0.1120	0.0008	0.0045	0.003	0.004
1	<0.001	<0.001	<0.0001	0.0001	27.4	32.4	0.0006	0.0013	10.29	12.58	2.7	3.1	0.0925	0.1121	0.0008	0.0045	0.003	0.004
2	<0.001	<0.001	<0.0001	0.0001	27.5	32.5	0.0006	0.0013	10.29	12.58	2.7	3.1	0.0925	0.1121	0.0008	0.0045	0.003	0.004
3	<0.001	<0.001	<0.0001	0.0001	27.4	32.4	0.0006	0.0013	10.28	12.57	2.7	3.1	0.0925	0.1121	0.0008	0.0045	0.003	0.004
4	<0.001	<0.001	<0.0001	0.0002	28.5	33.5	0.0007	0.0014	10.44	12.73	2.8	3.2	0.0954	0.1150	0.0008	0.0045	0.004	0.005
5	<0.001	<0.001	<0.0001	0.0001	27.9	32.9	0.0007	0.0014	10.35	12.64	2.8	3.2	0.0937	0.1133	0.0008	0.0045	0.003	0.004
7	<0.001	<0.001	<0.0001	0.0001	27.9	32.9	0.0007	0.0014	10.35	12.64	2.8	3.2	0.0938	0.1134	0.0008	0.0045	0.003	0.004
8	<0.001	<0.001	<0.0001	0.0002	28.2	33.2	0.0007	0.0014	10.40	12.69	2.8	3.2	0.0946	0.1142	0.0008	0.0045	0.003	0.004
9	<0.001	<0.001	<0.0001	0.0002	28.0	33.0	0.0007	0.0014	10.37	12.66	2.8	3.2	0.0941	0.1137	0.0008	0.0045	0.003	0.004
10	<0.001	<0.001	<0.0001	0.0001	27.9	32.9	0.0007	0.0014	10.35	12.64	2.8	3.2	0.0937	0.1133	0.0008	0.0045	0.003	0.004
11	<0.001	<0.001	<0.0001	0.0002	28.0	33.0	0.0007	0.0014	10.37	12.66	2.8	3.2	0.0941	0.1137	0.0008	0.0045	0.003	0.004
12	<0.001	<0.001	<0.0001	0.0001	27.9	32.9	0.0007	0.0014	10.35	12.64	2.8	3.2	0.0938	0.1134	0.0008	0.0045	0.003	0.004
13	<0.001	<0.001	<0.0001	0.0001	27.9	32.9	0.0007	0.0014	10.35	12.64	2.8	3.2	0.0937	0.1133	0.0008	0.0045	0.003	0.004

Table 2-22: Residual effects on water quality: construction period. Effects that begin during construction and continue to operation are addressed under operation

Environmental Effect	Mitigation/Enhancement	Residual Effect
Keeyask Area/Stephens Lake Area		
Increases in concentrations of total suspended solids (TSS), nutrients, metals, bacteria and levels of pH and decreases in dissolved oxygen (DO) could arise due to a variety of construction activities, including discharge of effluents, diversion and impoundment, clearing, instream construction, blasting, and/or due to accidental spills/releases.	A number of mitigation measures will be implemented to minimize effects of construction activities on water quality (see Table 2-12 for details).	Small to moderate in magnitude, small to large in spatial extent, and short-term.
Downstream Area Effects of Project construction on water quality downstream of Stephens Lake are related to effects on water quality upstream of the Kettle GS.	A number of mitigation measures will be implemented to minimize effects of construction activities on water quality (see Table 2-12 for details).	Small in magnitude, small to large in spatial extent, and short-term.
South Access Road Construction of the south access road (*i.e.*, installation of three culverts and clearing the Right of Way) may introduce sediments to the natural watercourses through erosion and/or resuspension of sediments.	Mitigation would include procedures described in the "Manitoba Stream Crossing Guidelines for the Protection of Fish and Fish Habitat" And the Keeyask South Access Road EnvPP.	None

Table 2-23: Residual effects on water quality for the protection of aquatic life: operation period

Environmental Effect	Mitigation/Enhancement	Residual Effect
Split Lake Area No effect	Project design to avoid water level effects to Split Lake.	None
Keeyask Area Water quality could be affected by: inputs of organic and inorganic materials through flooding and mineral shoreline erosion and peatland disintegration; changes in water residence times, depths, and velocities (conversion of river to reservoir); and alteration to the ice regime. Mainstem Area: Effects of flooding and mineral shoreline erosion on water quality are generally not expected to be detectable. The possible exception is mercury which may measurably increase. Due to the extremely low background concentrations and analytical detection limits, increases in total mercury may be detectable along the main flow of the reservoir. However, it is not expected that mercury or methylmercury will exceed Manitoba Water Quality Standards, Objectives and Guidelines (MWQSOGs) or Canadian Council of Ministers of the Environment (CCME) Protection of Aquatic Life (PAL) guidelines along the mainstem of the reservoir. Over the long-term, impoundment is predicted to cause decreases in concentrations of total suspended solids (TSS) and associated parameters such as particulate nutrients, turbidity, and some metals, although decreases may not be measurable under some flow conditions. Reductions in TSS will lead to increased water clarity along the main flow of the reservoir. This effect would continue for the life-span of the Project. The magnitude of Project decreases in TSS in the mainstem area of the reservoir vary according to flow condition; the range of predicted decreases exceeds the MWQSOG of a change of less than 5 mg/L from background but is within CCME PAL guidelines (which refer only to increases above background). Flooded Bays/Nearshore Environment: Water quality is expected to be measurably altered in off-current areas, notably over flooded terrestrial habitat. Concentrations of nutrients (nitrogen and phosphorus), organic carbon, true colour, TSS, turbidity, conductivity and metals will increase and pH and dissolved oxygen (DO) will decrease. Effects are expected to decrease along a gradient from shore out into the reservoir due to increased water volumes/dilution and mixing, decreased water residence times, and due to transitions from organic to mineral substrates. Effects are expected to be greatest in Year 1 of operation, declining thereafter. These areas are expected to develop hypoxic or anoxic conditions in winter, with portions of the nearshore areas developing DO conditions below Manitoba water quality objectives and CCME guidelines for the protection of aquatic life (PAL). As the period of ice cover is expected to increase relative to existing conditions, the duration of low DO events over winter will increase. In the open water season, DO may periodically decrease below PAL water quality objectives/guidelines under low wind events, most notably in shallow, flooded areas. In addition, DO depletion may occur in the vicinity of peat islands but would be dependent upon the location and spatial extent of the islands in the reservoir. Concentrations of nitrogen and phosphorus are expected to increase notably in nearshore areas. TP is expected to exceed at least one of the CCME phosphorus management framework triggers (>50% increase from background). However, in general it is expected that concentrations would remain within the current trophic status category of "eutrophic" in most or all of the flooded backbay areas. TSS is expected to increase in nearshore areas and to exceed the long-term Manitoba PAL water quality objective and CCME PAL guideline in some areas during Year 1 of operation. Predicted increases in TSS are below acutely toxic	Selection of 159 m reservoir elevation reduced proportion of newly flooded area in reservoir, thereby reducing areas with degraded water quality and reducing potential effect to water quality along the mainstem. Potential effects were further reduced by clearing of vegetation as described in the reservoir clearing plan developed by the KCN and Manitoba Hydro.	DO: Effects in the majority of the reservoir will be negligible year-round. Effects in flooded, nearshore habitat will range from small to large, medium term, small to medium in spatial extent, and of high frequency in the ice-cover season. Effects in the open water season in flooded, nearshore habitat will be negligible to small in magnitude under typical climatic conditions. Moderate to large effects are expected under infrequent low wind events in the flooded nearshore areas; these effects would be of low frequency, of medium duration, and small in spatial extent. TSS/Turbidity/Water Clarity: Effects in the offshore, mainstem of the reservoir will be negligible to moderate, long-term, and of high frequency (continuous) in most areas under low and median flow conditions. Large, short-term, frequent effects will occur in the flooded nearshore areas. Long-term effects will be negligible to moderate in most areas and under low and median flow conditions and of high frequency. TP and TN: Effects will be negligible (mainstem of the reservoir) to large (flooded, nearshore habitat), medium term, of small to medium spatial extent, and of high frequency. pH, organic carbon, true colour, TDS, and Conductivity: Effects will be negligible (mainstem of the reservoir) to small (flooded, nearshore habitat), of medium duration, small to medium in spatial extent, and of high frequency.

Table 2-23: Residual effects on water quality for the protection of aquatic life: operation period

Environmental Effect	Mitigation/Enhancement	Residual Effect
concentrations but may cause or contribute to sub-lethal stress in aquatic biota. The greatest effects would occur in the first year of operation when peatland disintegration will be highest and declining thereafter. In addition, the Project is expected to cause or contribute to exceedances of Manitoba and CCME PAL water quality guidelines for selenium and silver and increase the magnitude of exceedances of PAL guidelines for iron and aluminum in the flooded bays. The Project may also cause or contribute to exceedances of the CCME PAL guidelines for cadmium, copper, and zinc in flooded bays but is not expected to result in exceedances of MWQSOGs for PAL for these metals (which are higher than the CCME guidelines). Although it is predicted that pH will decrease in the nearshore areas, it is expected to remain within Manitoba and CCME PAL water quality guidelines. Water clarity will be reduced in nearshore areas due to increases in TSS, turbidity, dissolved organic carbon (DOC), and true colour due to peatland disintegration and flooding. These effects will decrease over time, being greatest in Year 1 of operation. The largest effects to water quality are expected in nearshore areas and these effects are expected to be greatest in the initial years of operation. As labile carbon in flooded organic materials is decomposed and as peatland disintegration declines after Year 1, effects to water quality will also decline. Effects related to flooding will also decline as organic substrate is converted to primarily mineral substrate over time. In general, on the basis of information gathered from other reservoirs, including Stephens Lake, effects to water quality in nearshore areas are expected to persist for approximately 10–15 years although localized effects may persist for > 30 years.		Metals: Effects will be negligible or small for most metals throughout the Study Area. Effects on iron and aluminum and potentially cadmium, copper, selenium, silver, mercury, methylmercury, and zinc, will be of moderate magnitude, small to medium in spatial extent (*i.e.*, in flooded habitat), and of medium duration.
Stephens Lake Area Water quality could be affected by a change in the quality of inflowing water from the Keeyask reservoir. It has been conservatively assumed that mercury and methylmercury concentrations may increase sufficiently to be detectable but both are expected to remain well below MWQSOGs and CCME PAL guidelines, and concentrations will decrease further in Stephens Lake. TSS and associated parameters (turbidity and particulate nutrients and metals) will be lower at the outflow of the GS and will decrease further for approximately 10–12 km downstream of the GS. At a distance of approximately 10–12 km downstream TSS is predicted to be similar to existing conditions and water quality will not be affected beyond this point. Effects are expected to be long-term (> 30 years). Nutrients and TSS may be increased in the immediate vicinity of the treated sewage effluent discharge during Project operation. TSS may also be increased by discharge of water treatment plant backwash. Effluent would comply with regulatory requirements and effects to water quality are not expected to extend beyond a site-specific spatial extent (*i.e.*, small). No effects are expected at the Kettle GS or near the Town of Gillam drinking water intake.	None	TSS/Turbidity/Water Clarity: Effects will be small to moderate (depending on flow conditions), long-term, medium spatial extent, and of high frequency. TP and metals: Effects will be negligible to small, long-term, medium spatial extent, and frequent. Effects to TN, DO, pH, organic carbon, true colour, and conductivity/TDS will be negligible.
Downstream Area No effect	None	None
North and South Access Road streams Potential stream bank and streambed erosion and drainage from roadside ditches could increase suspended sediments near the crossings.	Streambank and streambed erosion reduced through use of a clear span bridge on Looking Back Creek and appropriately sized and positioned culverts as per Manitoba Stream Crossing Guidelines. Sediment inputs from runoff reduced by erosion and sediment control measures.	Negligible

Table 2-24: Mean and standard error (SE) of metals in triplicate samples of surficial sediments (µg/g dry weight, upper 5 cm) collected from selected lakes on the Nelson River system between Kelsey and Kettle generating stations in 2001 and 2002 and comparison to sediment quality guidelines. Means indicated in blue and red exceed Manitoba sediment quality guidelines (SQGs) and probable effect levels (PELs) for sediments, respectively (MWS 2011). Means indicated in blue and red italics exceed the Ontario lowest effect level (LEL) and the severe effect level (SEL) for sediments, respectively (Persaud *et al.* 1993)

Sample Location	Location ID	Year		Metals (µg/g d.w.)																	
				Aluminum	Arsenic	Barium	Beryllium	Bismuth	Boron	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel
Analytical Detection Limit				3	0.03	0.04	0.06	0.02	0.6	0.02	7	0.1	0.01	0.2	6	0.05	2	0.03	0.02	0.02	0.2
Split Lake	SPL-7	2001	Mean	8,490	2.79	91.43	0.38	0.16	5.9	0.03	45,200	25.3	7.88	15.5	15,533	11.04	26,900	*603*	0.03	0.37	*23.8*
			SE	316	0.14	6.87	0.02	0.01	0.2	0.01	1,353	0.8	0.20	0.4	433	2.44	1,137	63	0.00	0.08	0.4
		2002	Mean	10,110	4.56	119.17	0.47	0.12	6.7	0.13	79,200	28.4	8.53	17.6	18,900	7.62	22,567	*636*	-	0.33	*23.9*
			SE	1554	1.03	17.05	0.07	0.02	0.8	0.01	14,476	4.3	0.94	2.9	3,107	0.55	1,862	104	-	0.05	2.6
Gull Lake	GL-2	2001	Mean	4,340	1.08	30.20	0.16	0.06	<0.6	0.04	14,900	11.6	3.75	5.3	6,403	3.13	8,400	147	<0.02	0.11	9.5
			SE	151	0.09	1.40	0.01	0.00	-	0.00	2,318	0.5	0.21	0.3	165	0.06	412	10	-	0.01	0.4
		2002	Mean	5,077	4.46	57.07	0.19	0.04	5.1	0.07	72,300	19.8	4.97	19.5	14,567	5.08	18,833	373	-	1.12	*17.9*
			SE	272	0.39	9.02	0.03	0.02	0.6	0.01	15,595	1.8	0.24	4.6	2,122	0.61	2,497	24.6	-	0.50	2.2
Stephens Lake	STL-1	2001	Mean	10,600	2.74	81.80	0.45	0.14	5.1	0.11	69,733	25.7	7.81	15.5	16,233	7.28	25,967	*484*	0.02	0.17	*20.9*
			SE	351	0.10	2.65	0.01	0.00	0.3	0.00	713	0.9	0.17	0.3	713	0.09	784	46	0.00	0.01	0.8
		2002	Mean	10,833	4.35	111.53	0.47	0.19	6.9	0.15	69,900	39.7	9.74	35.2	*25,967*	99.27	25,667	*712*	-	1.83	*36.3*
			SE	1,185	0.09	13.78	0.07	0.08	0.5	0.03	10,134	0.7	0.72	3.4	296	75.97	437	53.5	-	0.42	0.3
Manitoba Sediment Quality Guidelines																					
SQG					5.9					0.6		37.3		35.7		35			0.17		
PEL					17					3.5		90.0		197		91.3			0.486		
Ontario Sediment Quality Guidelines																					
LEL															*20000*			*460*			*16*
SEL															*40000*			*1100*			*75*

Table 2-24: Mean and standard error (SE) of metals in triplicate samples of surficial sediments (µg/g dry weight, upper 5 cm) collected from selected lakes on the Nelson River system between Kelsey and Kettle generating stations in 2001 and 2002 and comparison to sediment quality guidelines. Means indicated in blue and red exceed Manitoba sediment quality guidelines (SQGs) and probable effect levels (PELs) for sediments, respectively (MWS 2011). Means indicated in blue and red italics exceed the Ontario lowest effect level (LEL) and the severe effect level (SEL) for sediments, respectively (Persaud *et al.* 1993)

Sample Location	Location ID	Year		Metals (µg/g d.w.)										
				Potassium	**Selenium**	**Silver**	**Sodium**	**Strontium**	**Thallium**	**Tin**	**Titanium**	**Uranium**	**Vanadium**	**Zinc**
Analytical Detection Limit				7	0.1	1	2	0.02	0.2	4	0.03	0.006	0.06	2
Split Lake	SPL-7	2001	Mean	1717	0.2	<1	160	28.9	<0.2	<4	672	0.692	22.0	33
			SE	78	0.0	-	4	0.8	-	-	20	0.012	0.7	1
		2002	Mean	2187	0.2	< 1	322	67.27	< 0.2	< 4	682	0.793	26.90	40
			SE	454	0.1	-	68	16.24	-	-	84	0.074	3.74	5
Gull Lake	GL-2	2001	Mean	728	<0.1	<1	67	11.8	<0.2	<4	399	0.413	11.0	17
			SE	33	-	-	3	0.9	-	-	7	0.005	0.3	1
		2002	Mean	892	0.1	< 1	178	48.60	< 0.2	< 4	478	0.602	17.17	19
			SE	132	0.0	-	26	3.17	-	-	37	0.072	0.12	3
Stephens Lake	STL-1	2001	Mean	1953	<0.1	<1	163	47.3	<0.2	<4	699	0.677	23.9	38
			SE	63	-	-	3	0.9	-	-	27	0.006	0.7	1
		2002	Mean	2440	0.1	< 1	230	54.33	0.1	< 4	744	0.836	28.37	49
			SE	270	0.1	-	17	3.24	0.0	-	55	0.056	1.92	8
Manitoba Sediment Quality Guidelines														
SQG														123
PEL														315
Ontario Sediment Quality Guidelines														
LEL														
SEL														
B.C. Ministry of Environment Sediment Quality Guidelines					2.0									

Table 2-25: Concentrations of total mercury measured in moss/peat/litter in unflooded soil horizons from 13 sites along the Churchill River Diversion route (1981–1982; Bodaly *et al.* 1987) and mean concentrations of mercury in Keeyask peat and Gull Lake sediments

Site/Area	Year	Total Mercury (ug/g d.w.)		
		Unflooded Peat/moss/litter	Flooded Moss/Peat/Litter	Sediments
Southern Indian Lake (Area 5)	1981	0.099	0.083	0.017
	1982	0.115	0.158	
Southern Indian Lake (Area 4)	1981	0.109	0.067	0.009
	1982	0.068	0.080	
Southern Indian Lake (Methyl Bay)	1982	0.104	0.117	
Southern Indian Lake (Sandhill Bay)	1981	0.110	0.088	0.014
Southern Indian Lake (Wupaw Bay)	1981	0.114	-	0.053
Southern Indian Lake (Area 6)	1981	0.083	-	0.045
Issett Lake	1981	0.057	0.100	0.050
Granville Lake	1981	0.119	-	0.024
	1982	0.156	-	
West Mynarski Lake	1981	0.115	0.068	0.058
	1982	0.207	-	
Central Mynarski Lake	1981	0.085	-	0.015
East Mynarski Lake	1981	0.055	-	0.020
	1982	0.062	-	
Notigi Lake (west basin)	1981	0.052	0.047	0.028
	1982	0.069	-	
Notigi Lake (east basin)	1981	0.169	-	0.014
Footprint Lake	1981	0.079	0.094	0.060
Summary Statistics	Mean	0.101	0.090	0.031
	Median	0.102	0.086	0.024
	Minimum	0.052	0.047	0.009
	Maximum	0.207	0.158	0.060
Keeyask[1]	2001	-	-	<0.02
	2004	0.155	-	-

1. Mean for sediments is from Gull Lake and "unflooded peat/moss/litter" reflects surface peat measured in the Keeyask area.

Table 2-26: Residual effects on sediment quality: construction period. Effects that begin during construction and continue to operation are addressed under operation

Environmental Effect	Mitigation/Enhancement	Residual Effect
Generating Station Infrastructure Sediment quality could be affected by Project construction due to introduction of nutrients, metals, and other contaminants to surface waters.	See measures to mitigate effects to water quality.	Negligible due to implementation of mitigation measures.
South Access Road Sediment quality could be affected by construction of the south access road due to introduction of nutrients, metals, and other contaminants to surface waters.	See measures to mitigate effects to water quality.	Negligible due to implementation of mitigation measures.

Table 2-27: Residual effects on sediment quality: Operation period

Environmental Effect	Mitigation/Enhancement	Residual Effect
Split Lake Area No effect	Project design to avoid water level effects to Split Lake.	None
Keeyask Area Sediment quality is affected as currently terrestrial soils will be flooded and become aquatic sediments. Concentrations of total metals in surface peat are largely lower than the average concentrations measured in existing aquatic sediments as well as being below Manitoba (or other available) sediment quality guidelines [SQGs]). Therefore, flooding should not result in exceedances of SQGs. Mercury is notably higher in peat than current sediments and it is expected that post-flood more mercury will be converted to methylmercury. However, total mercury in peat is below Manitoba SQGs. The expected duration of effects are approximately 30 years – the approximate time estimated for conversion of most flooded organic substrate to mineral substrate through deposition of mineral material from the water column. Effects may persist for longer periods in localized nearshore areas where substrates remain primarily organic.	None	Negligible to small, long-term, small in geographic extent, frequent.
Stephens Lake Area Sediment quality could be affected by a change in inflowing water from the reservoir. No substantive changes in long-term water quality conditions at the outflow are anticipated. Therefore, no effects to sediment quality in Stephens Lake are expected.	None	None

Table 2-27: Residual effects on sediment quality: Operation period

Environmental Effect	Mitigation/Enhancement	Residual Effect
Downstream Area No effects are expected.	None	None
Access Road streams Sediment quality could be affected due to sediment inputs from roadside ditches as well as particulate matter from vehicles, *etc.*	Erosion control measures to prevent sediment inputs.	Negligible

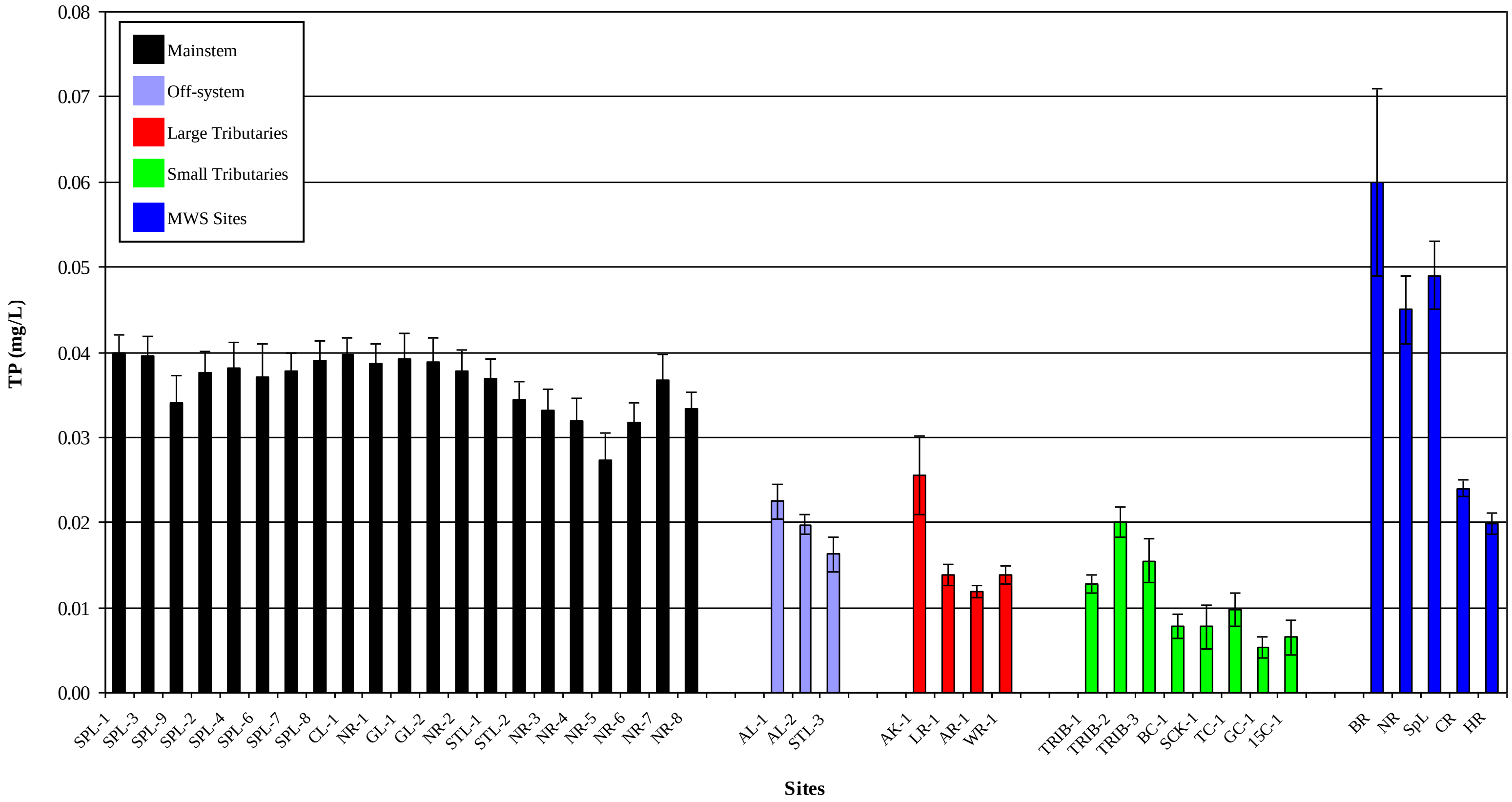

Figure 2-1: **Open water season mean (±standard error) total phosphorus (TP) concentrations measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995**

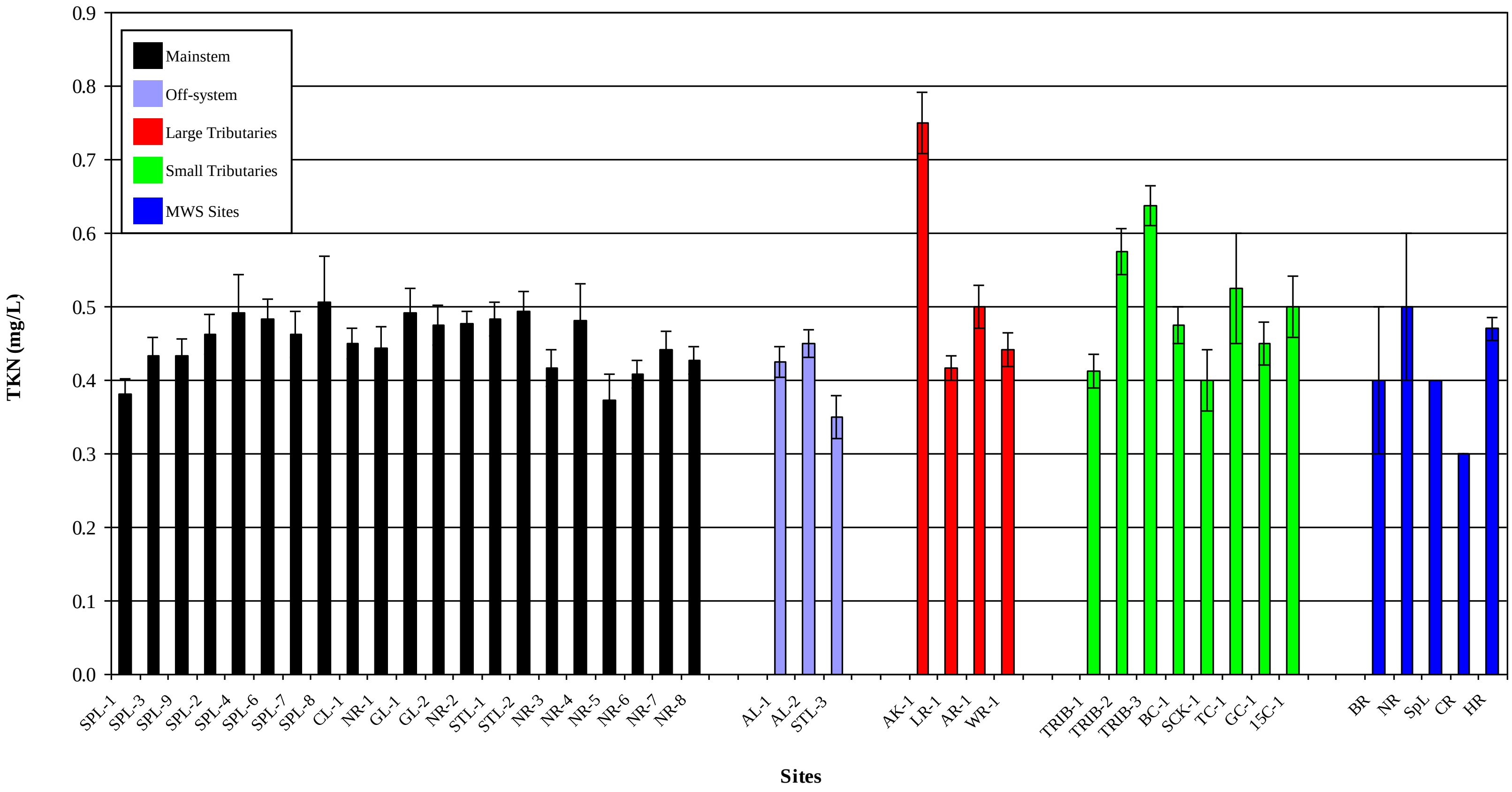

Figure 2-2: Open water season mean (±standard error) total Kjeldahl nitrogen (TKN) measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995

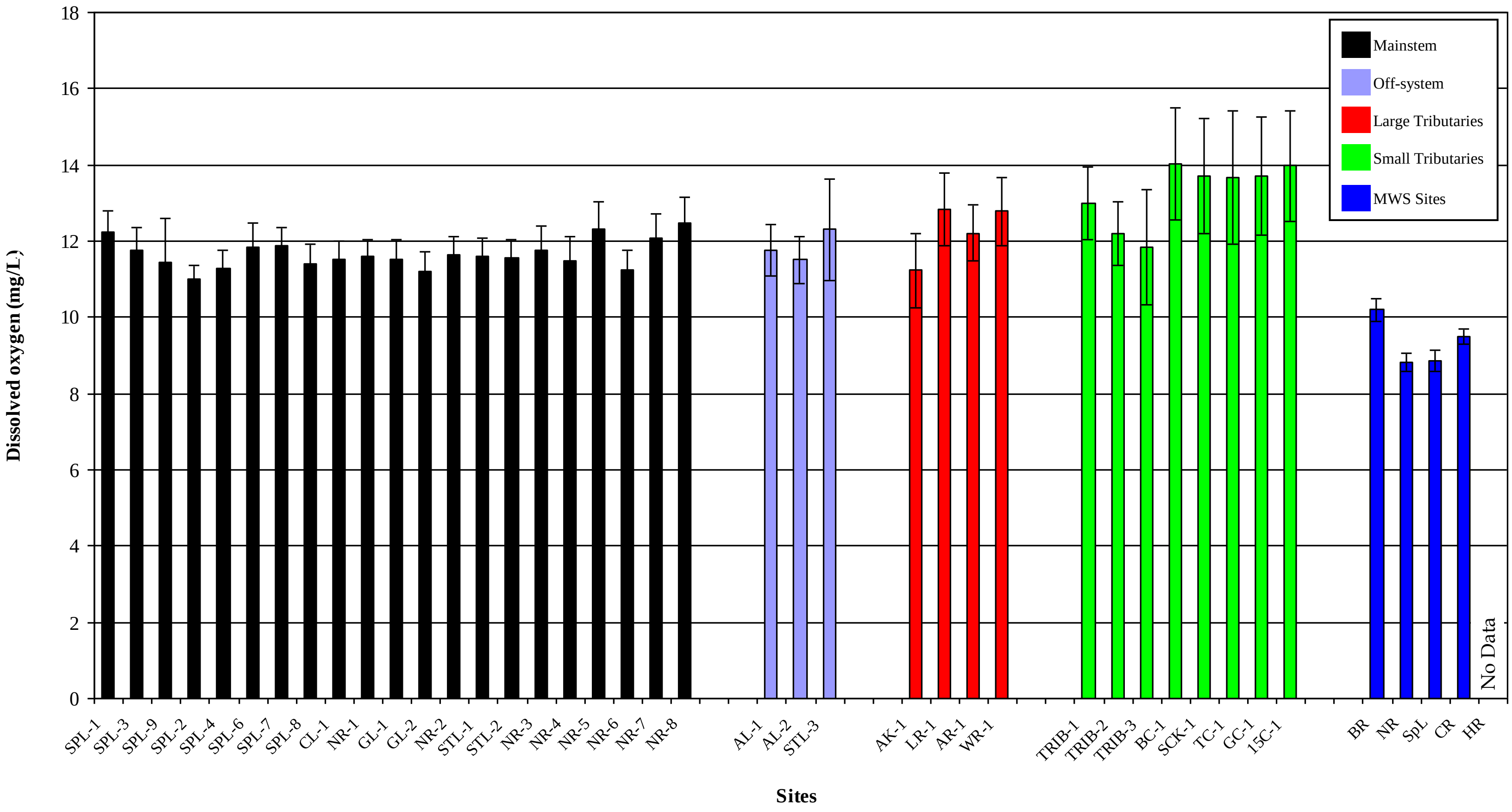

Figure 2-3: Open water season mean (±standard error) dissolved oxygen concentrations measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL). Means for MWS sites represent the period of 1997–2006

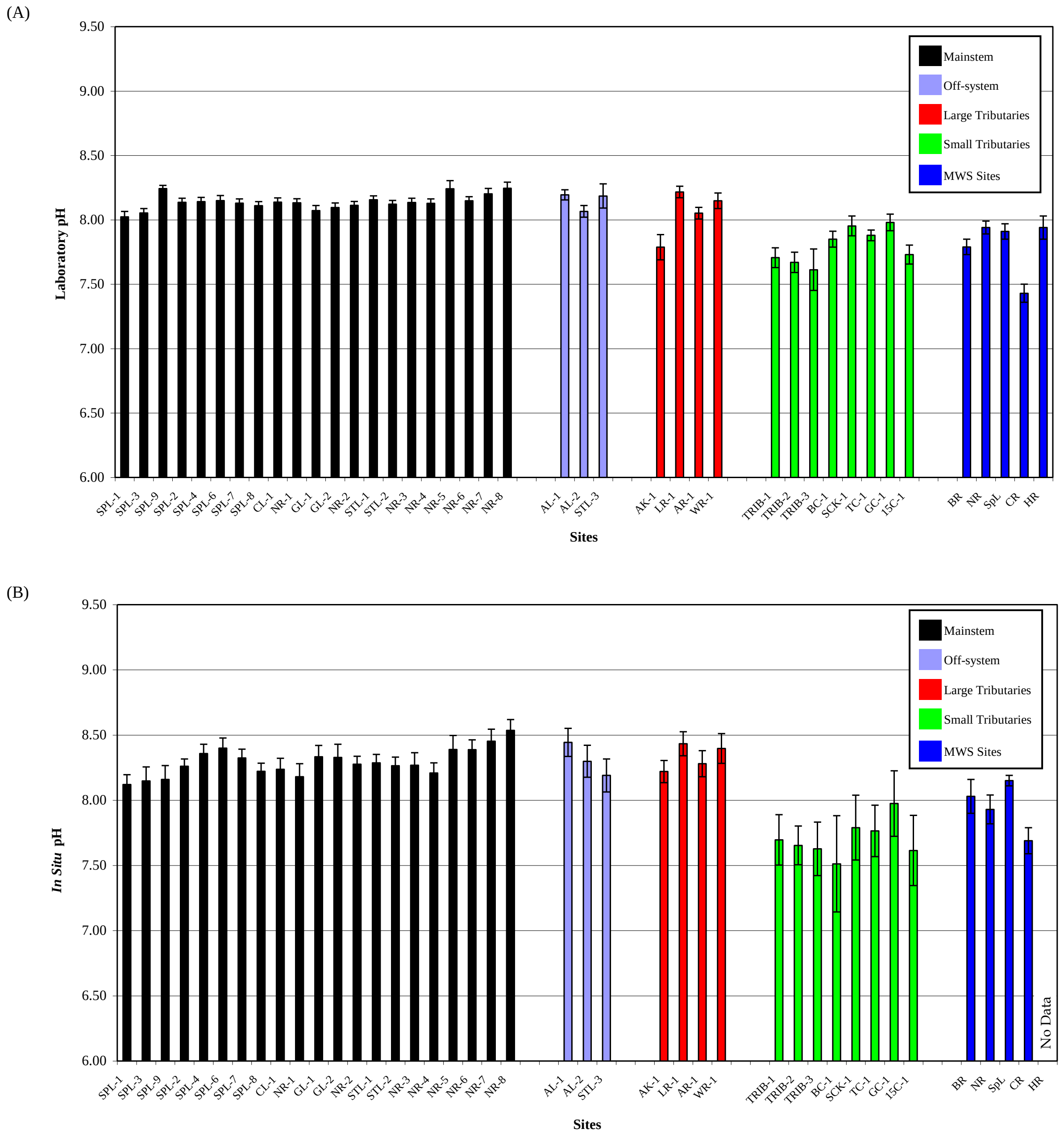

Figure 2-4: Open water season mean (±standard error) (A) laboratory pH and (B) *in situ* pH measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995

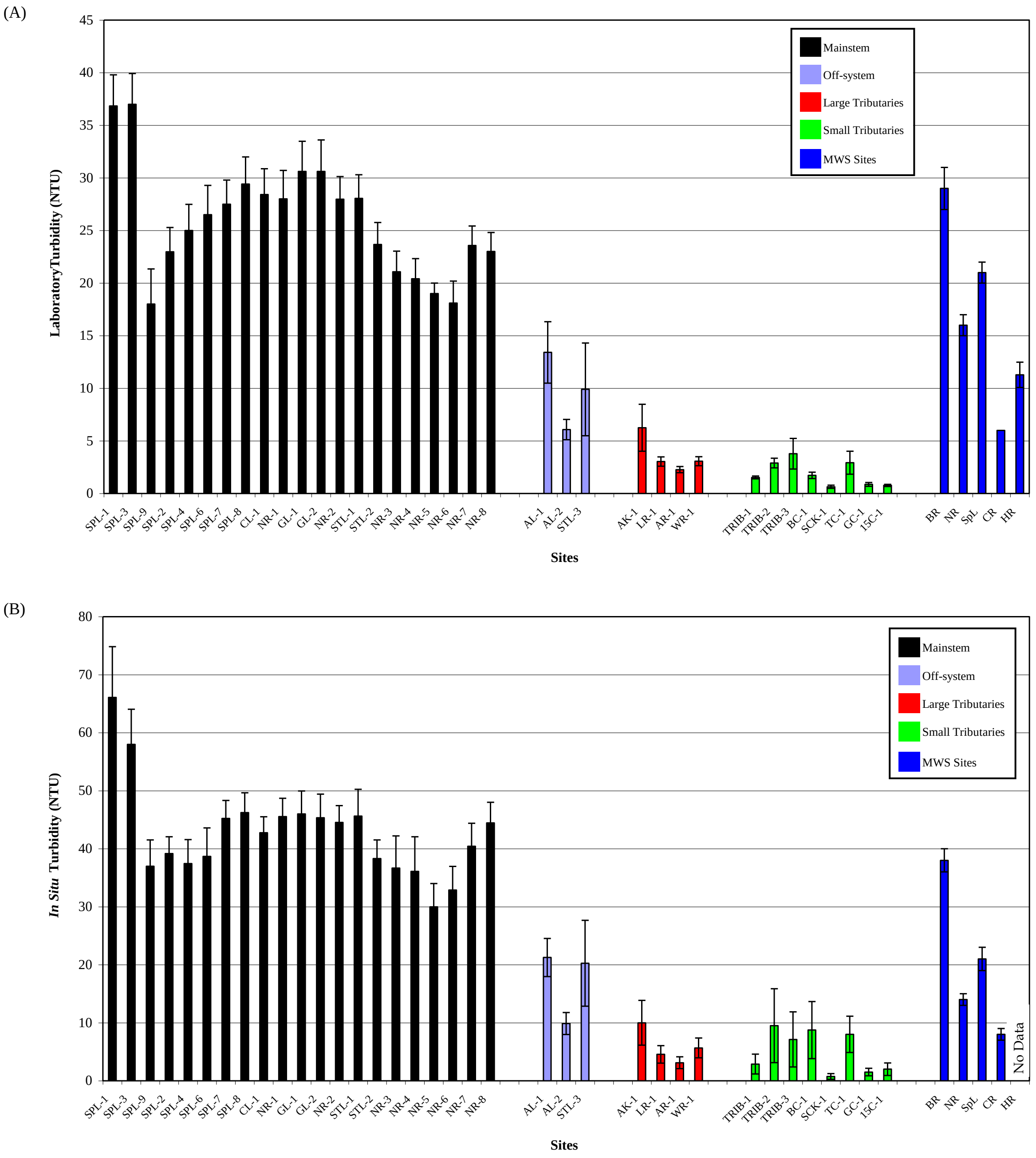

Figure 2-5: **Open water season mean (±standard error) (A) laboratory and (B) *in situ* turbidity values measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995**

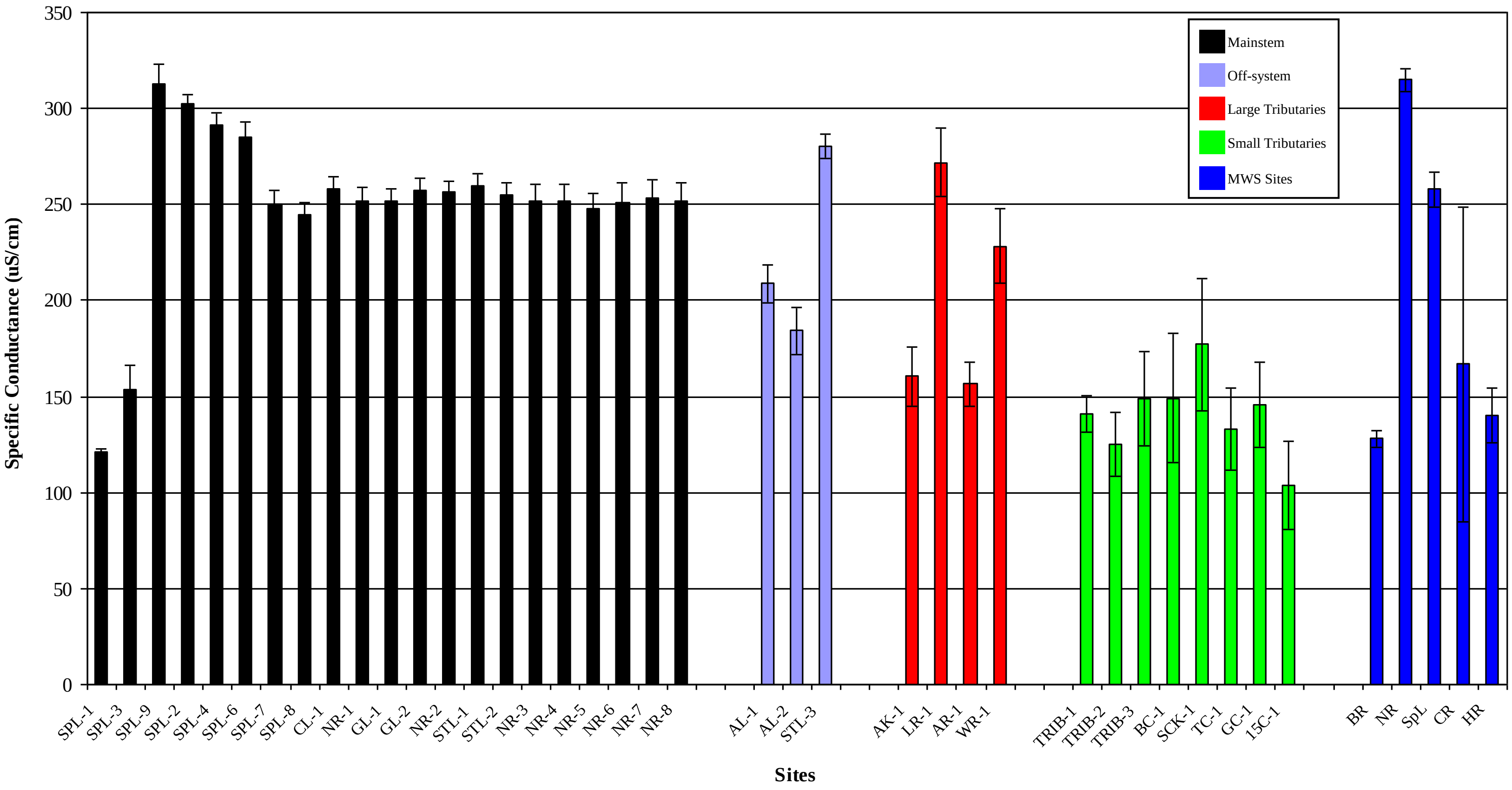

Figure 2-6: **Open water season mean (±standard error) specific conductance values measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries (*in situ*), and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River (laboratory). Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995**

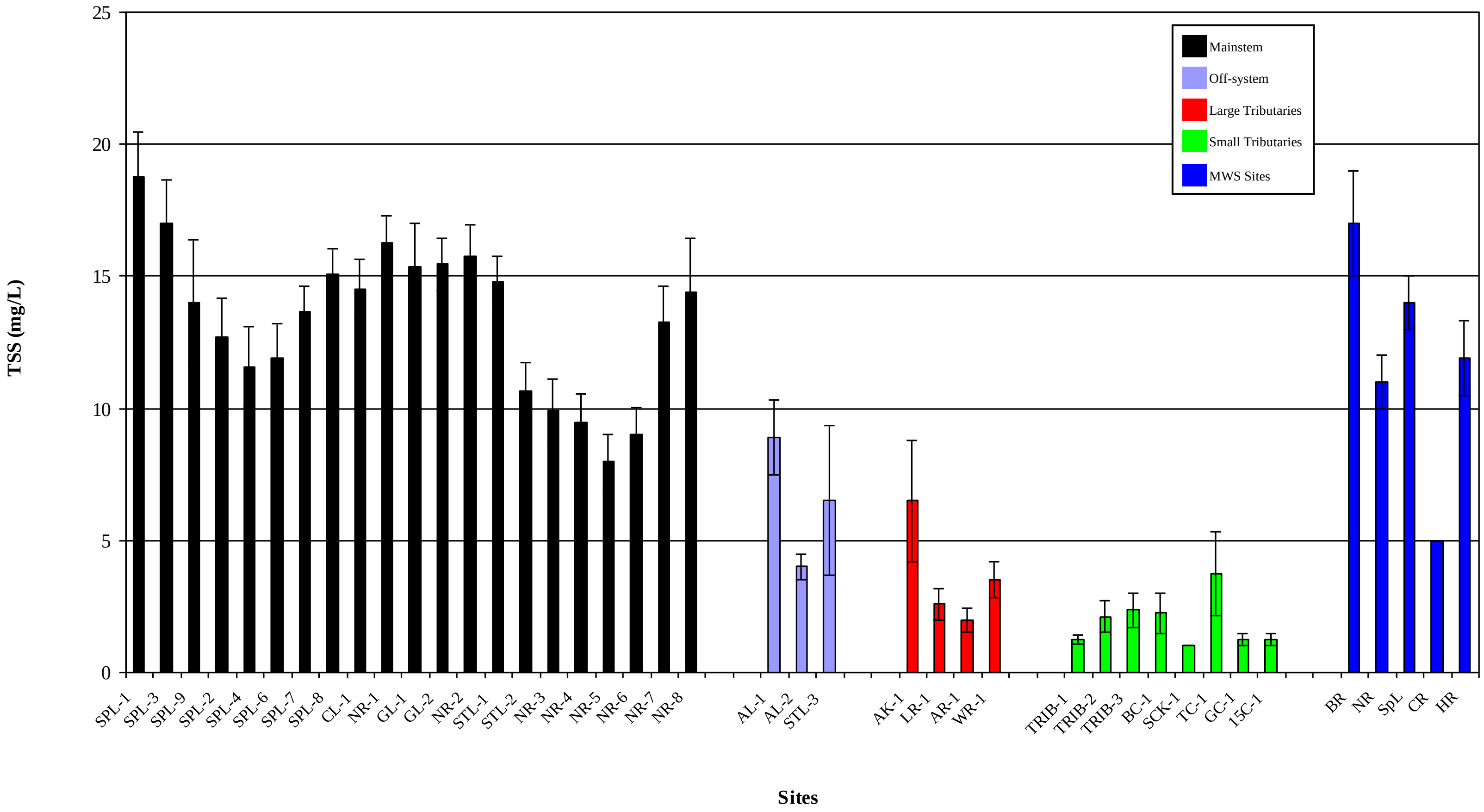

Figure 2-7: **Open water season mean (±standard error) total suspended solids (TSS) concentrations measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995**

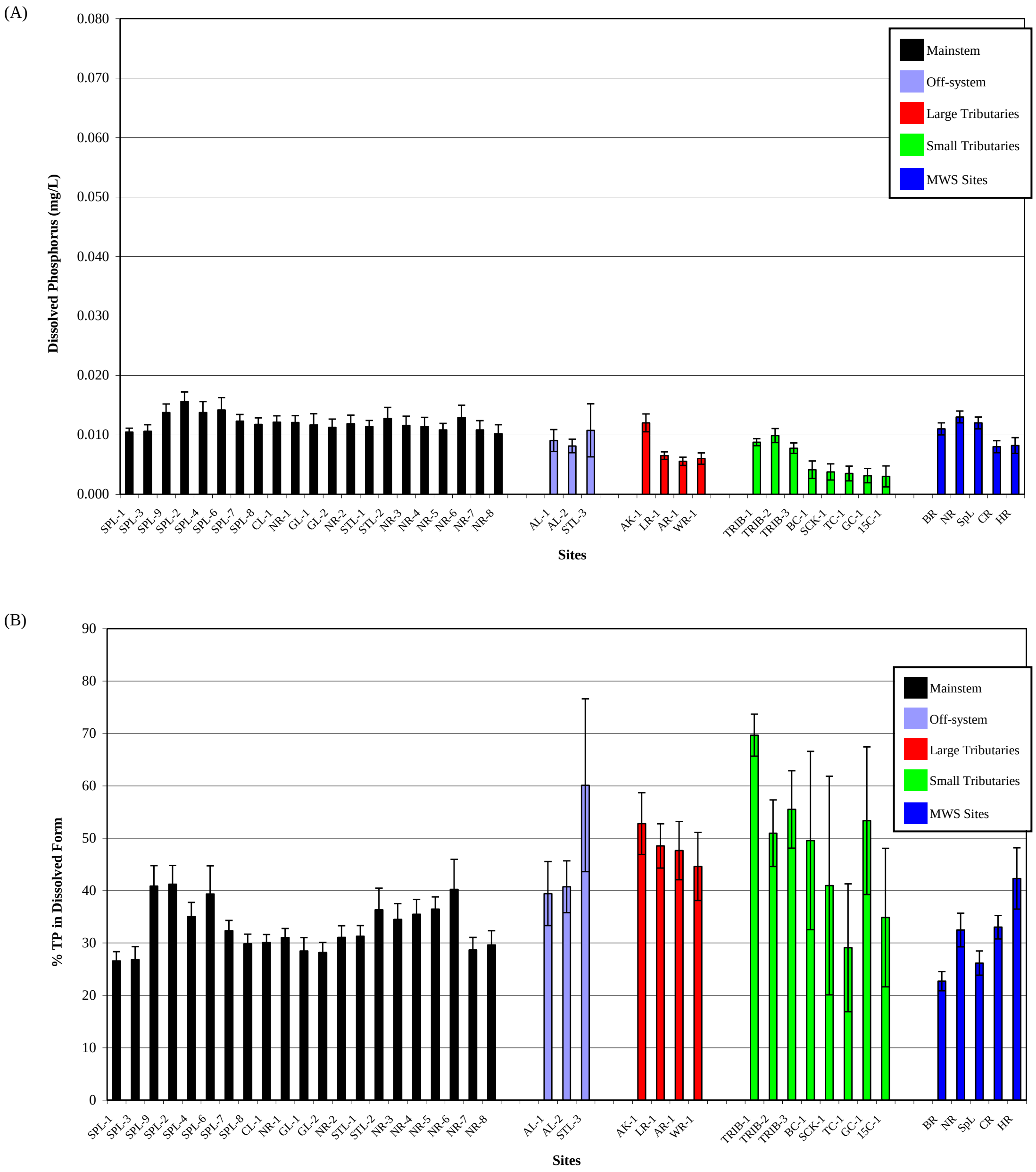

Figure 2-8: Open water season mean (±standard error) (A) concentrations of total dissolved phosphorus and (B) percent total phosphorus (TP) in dissolved form measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995

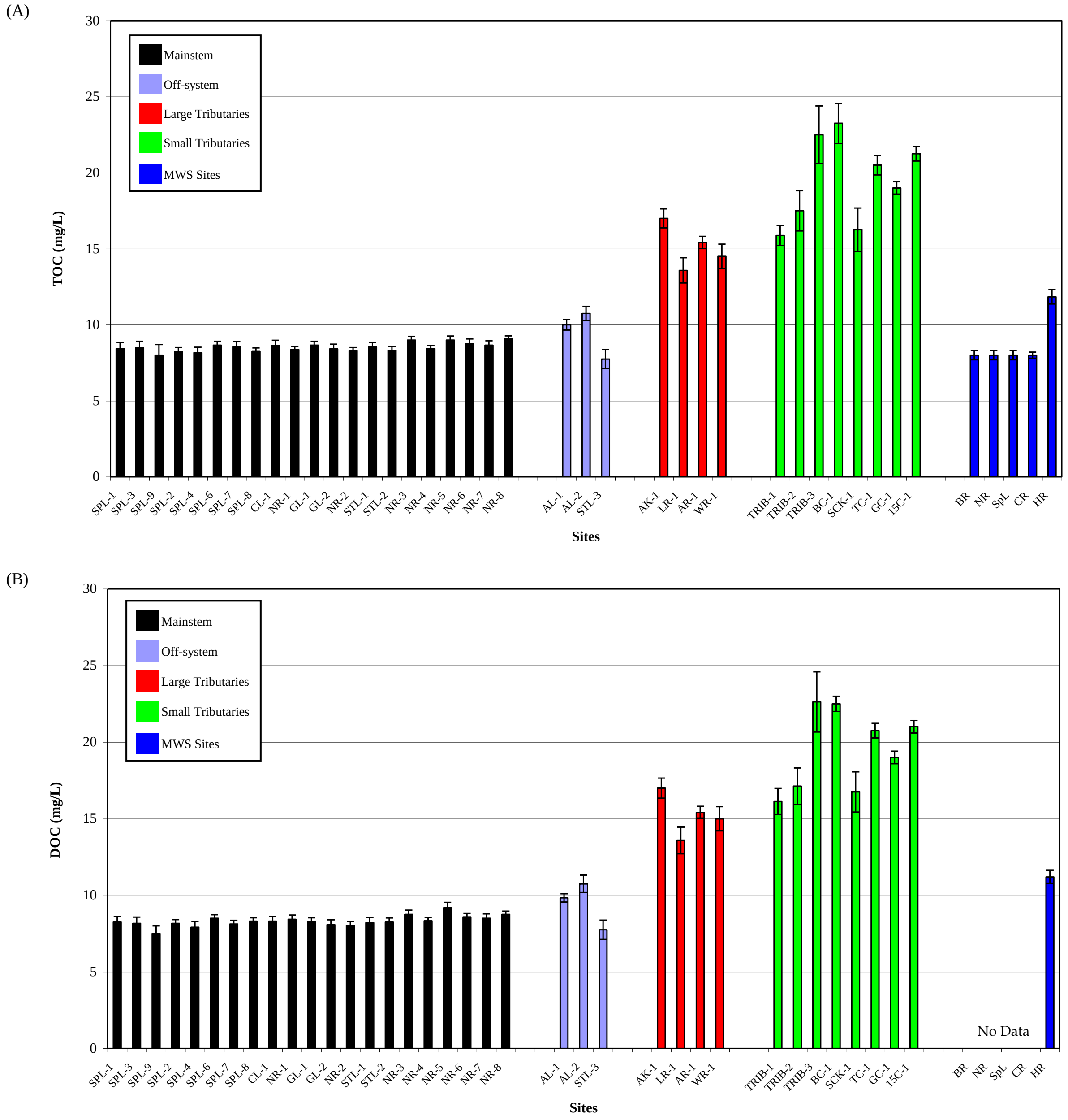

Figure 2-9: **Open water season mean (±standard error) (A) total organic carbon (TOC) and (B) dissolved organic carbon (DOC) concentrations measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995**

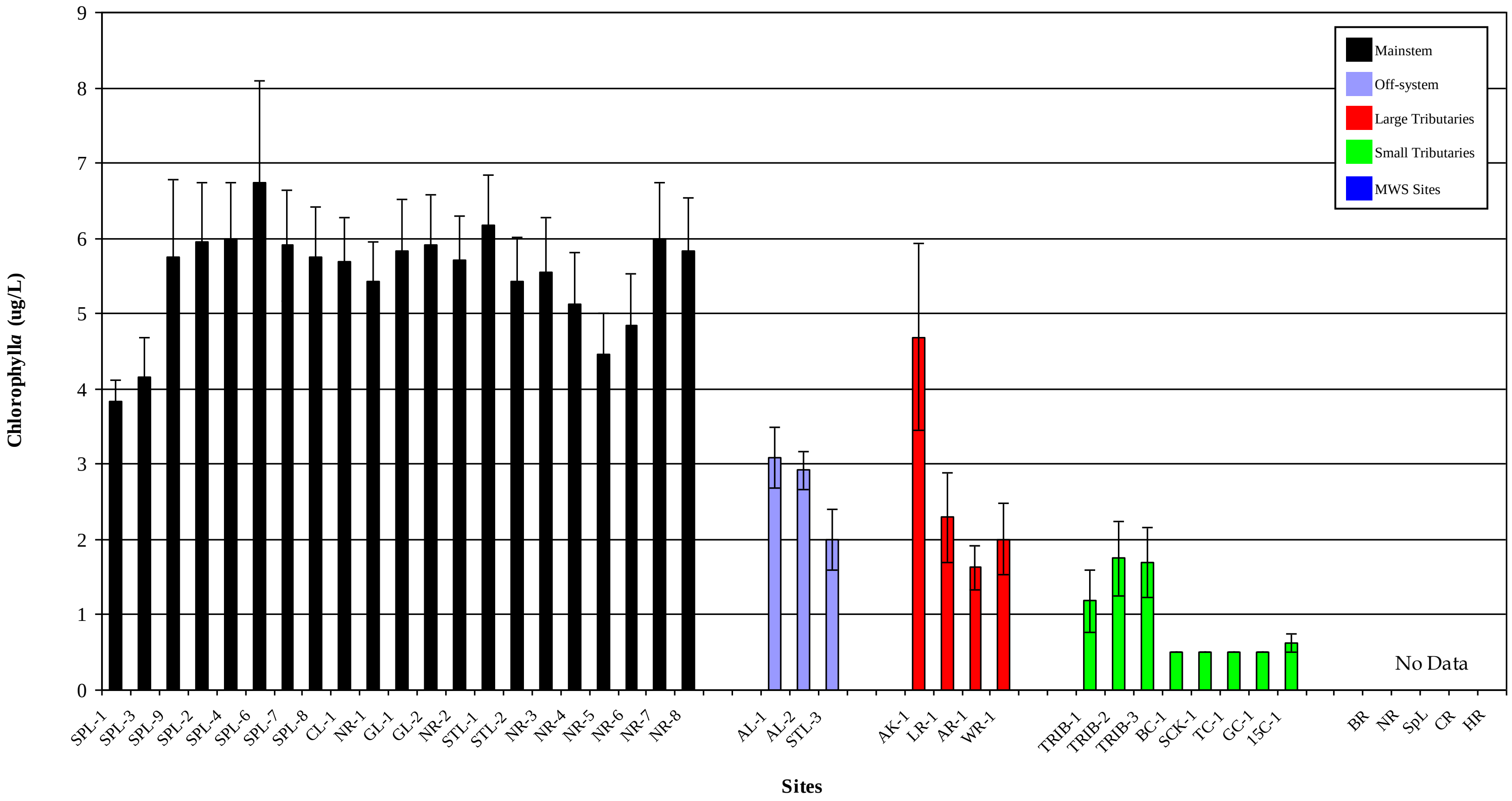

Figure 2-10: Open water season mean (±standard error) chlorophyll *a* concentrations measured at sites located on the mainstem of the lower Nelson River, off-system sites, large tributaries, small tributaries, and Manitoba Water Stewardship (MWS) monitoring sites in the Burntwood River (BR) at Thompson, the Nelson River (NR) at Sipiwesk Lake, the Churchill River (CR) and at Granville Lake (GL), and the historical Environment Canada site on the Hayes River (HR) at God's River. Means for MWS sites represent the period of 1997–2006 and the mean for the Hayes River represents the period of 1993–1995.

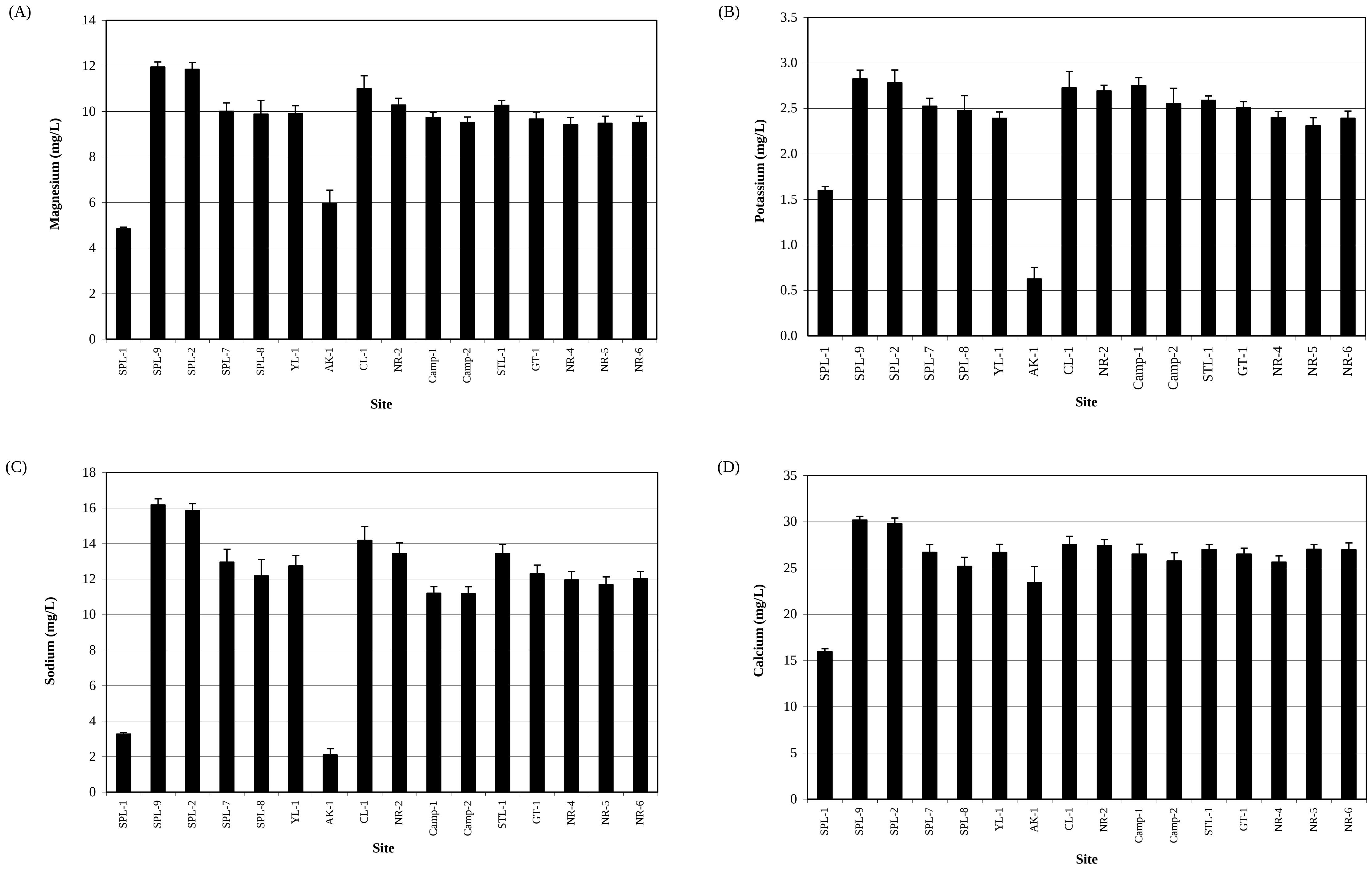

Figure 2-11: Open water season mean (±standard error) concentrations of (A) magnesium, (B) potassium, (C) sodium, and (D) calcium measured at sites in the Aquatic Environment Study Area: 2001–2004

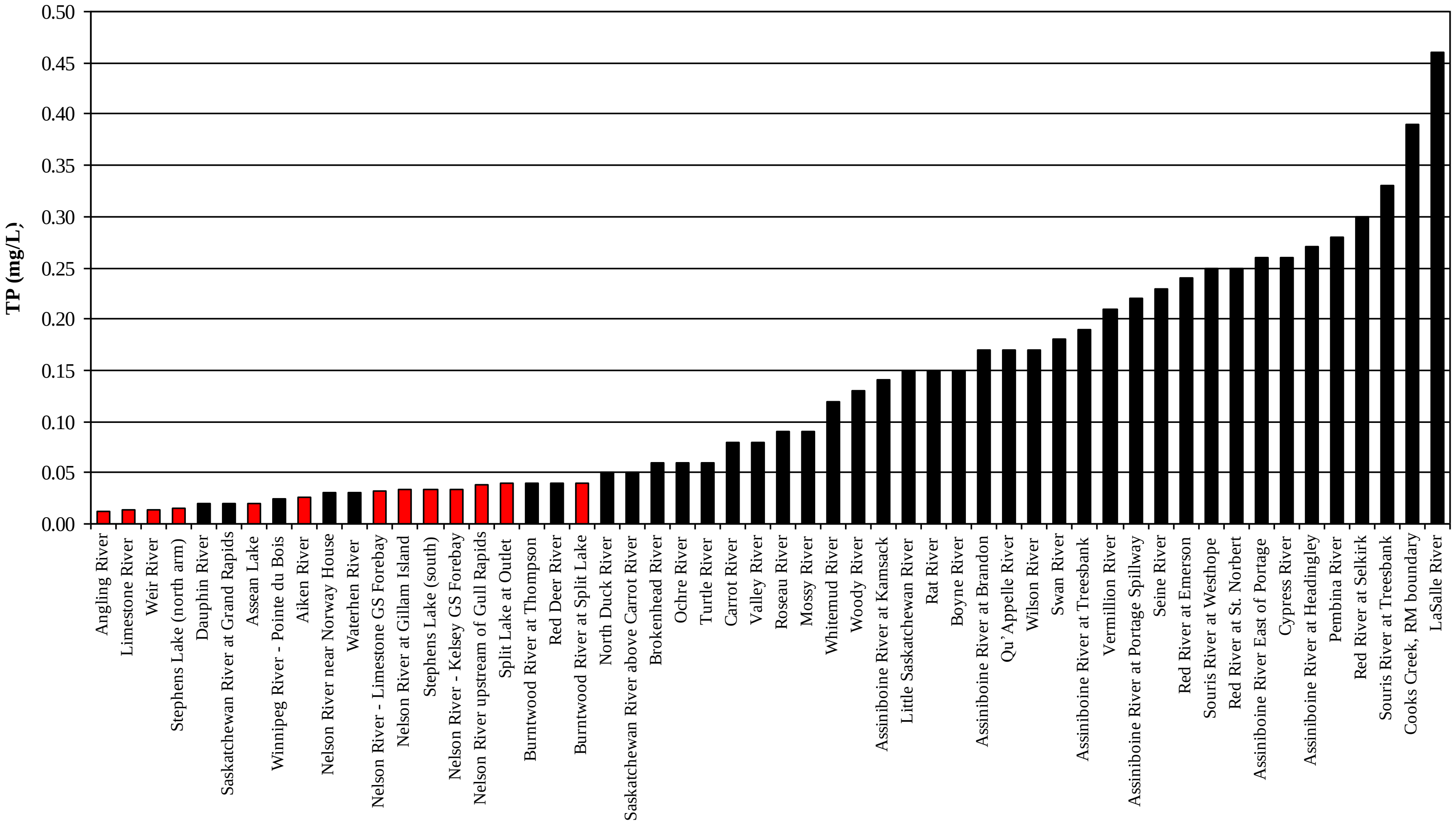

Figure 2-12: Total phosphorus (TP) concentrations measured at lakes and rivers in Manitoba. Black bars represent mean concentrations (1994–2001) measured at Manitoba Water Stewardship monitoring sites (North/South Consultants 2006). Red bars represent mean (2001–2004) concentrations measured at sites during the Keeyask environmental studies

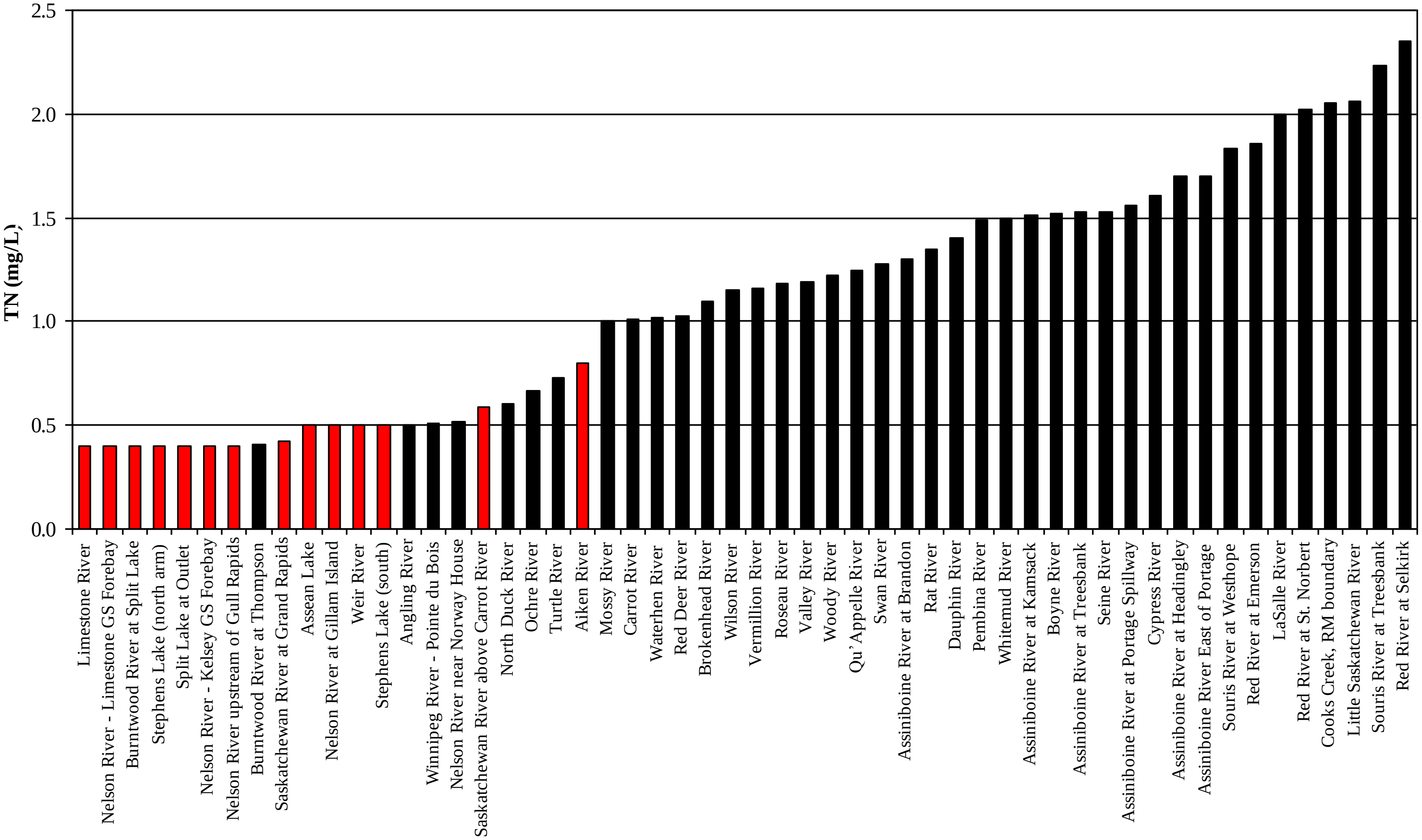

Figure 2-13: **Total nitrogen (TN) concentrations measured at lakes and rivers in Manitoba. Black bars represent mean concentrations (1994–2001) measured at Manitoba Water Stewardship monitoring sites (North/South Consultants 2006). Red bars represent mean (2001–2004) concentrations measured at sites during the Keeyask environmental studies**

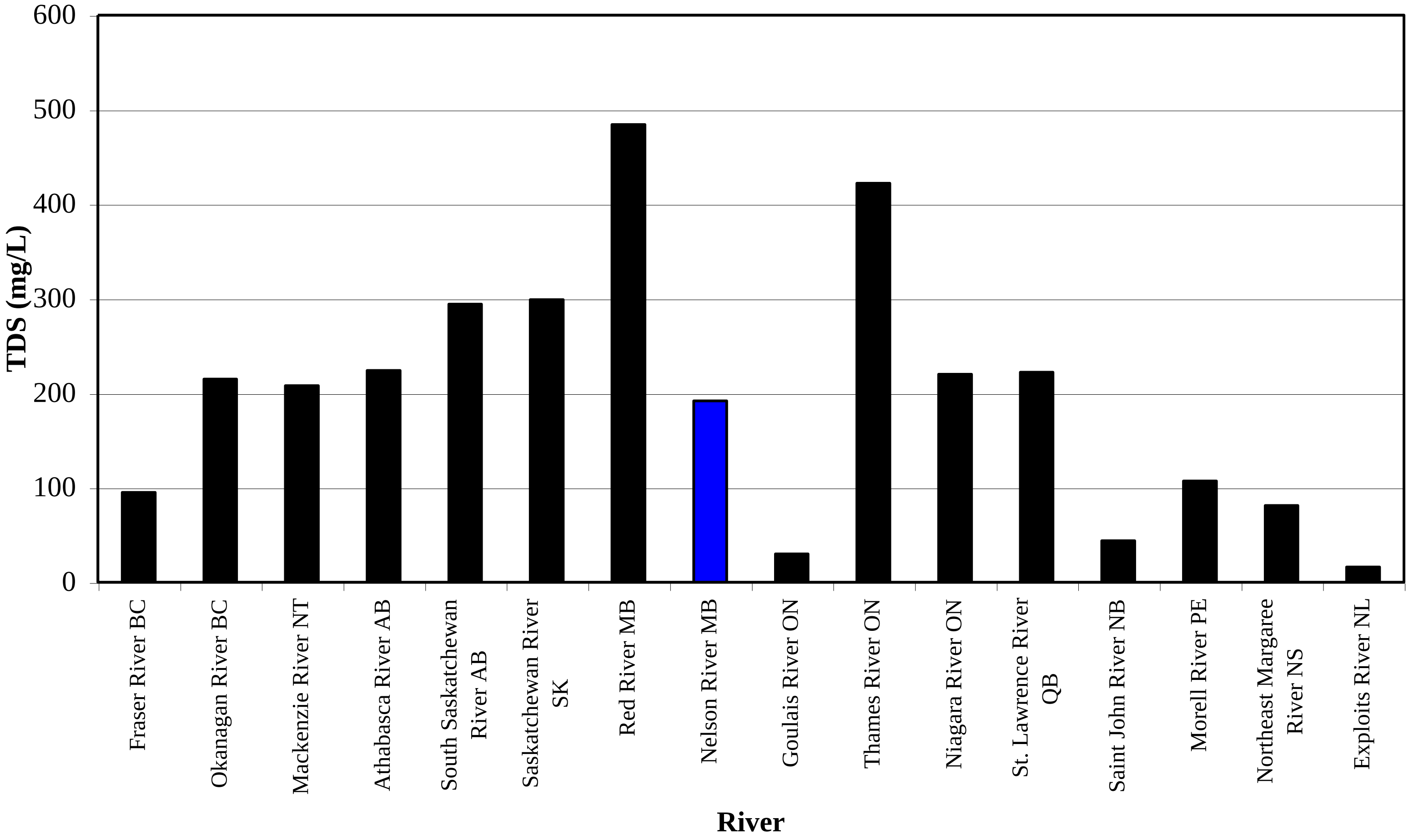

Figure 2-14: Concentrations of total dissolved solids (TDS) in selected Canadian Rivers. Data obtained from Environment Canada (2010)

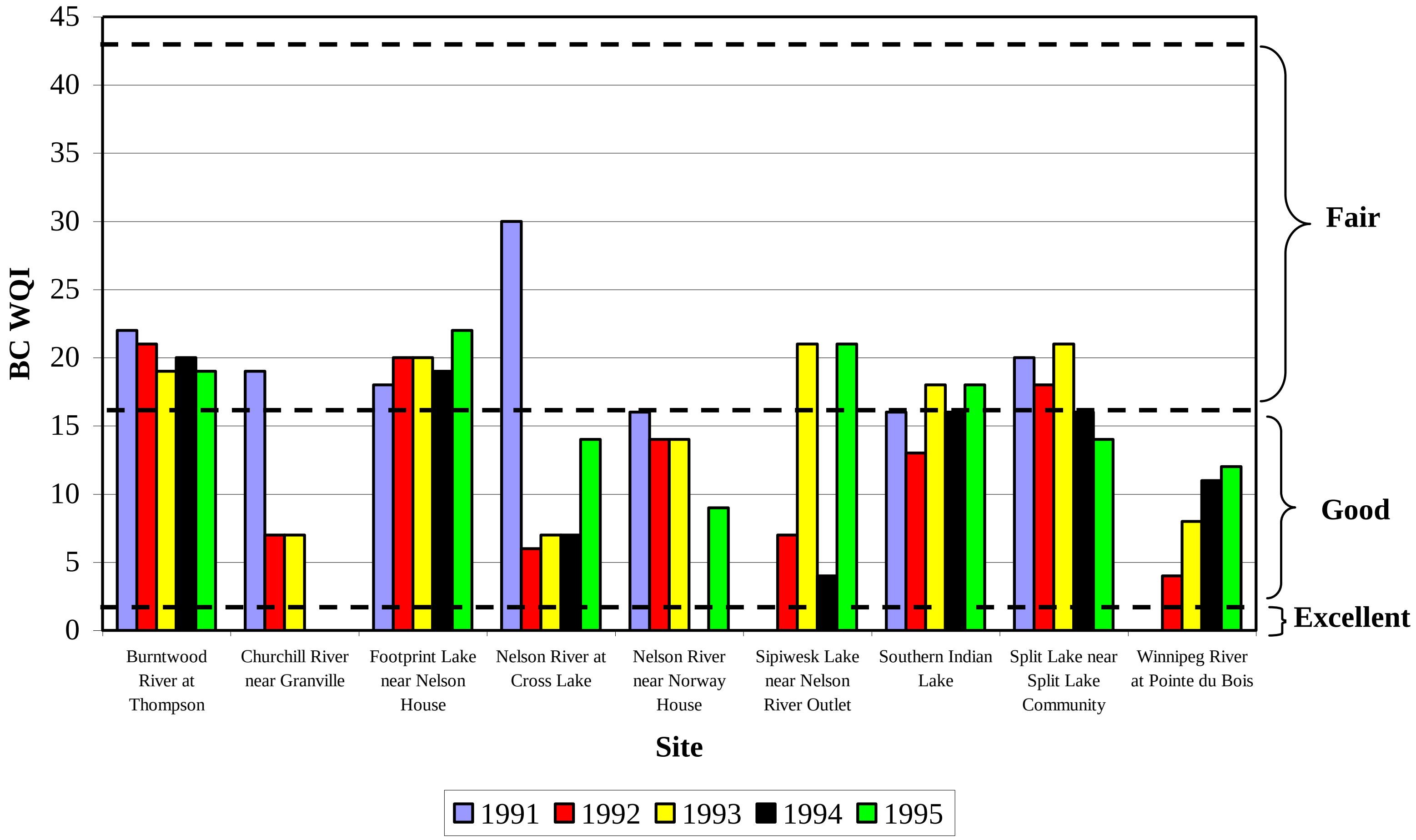

Figure 2-15: **British Columbia Water Quality Index (BC WQI) values for selected Manitoba Water Stewardship (MWS) water quality monitoring sites: 1991–1995. Data obtained from Manitoba Environment (1997)**

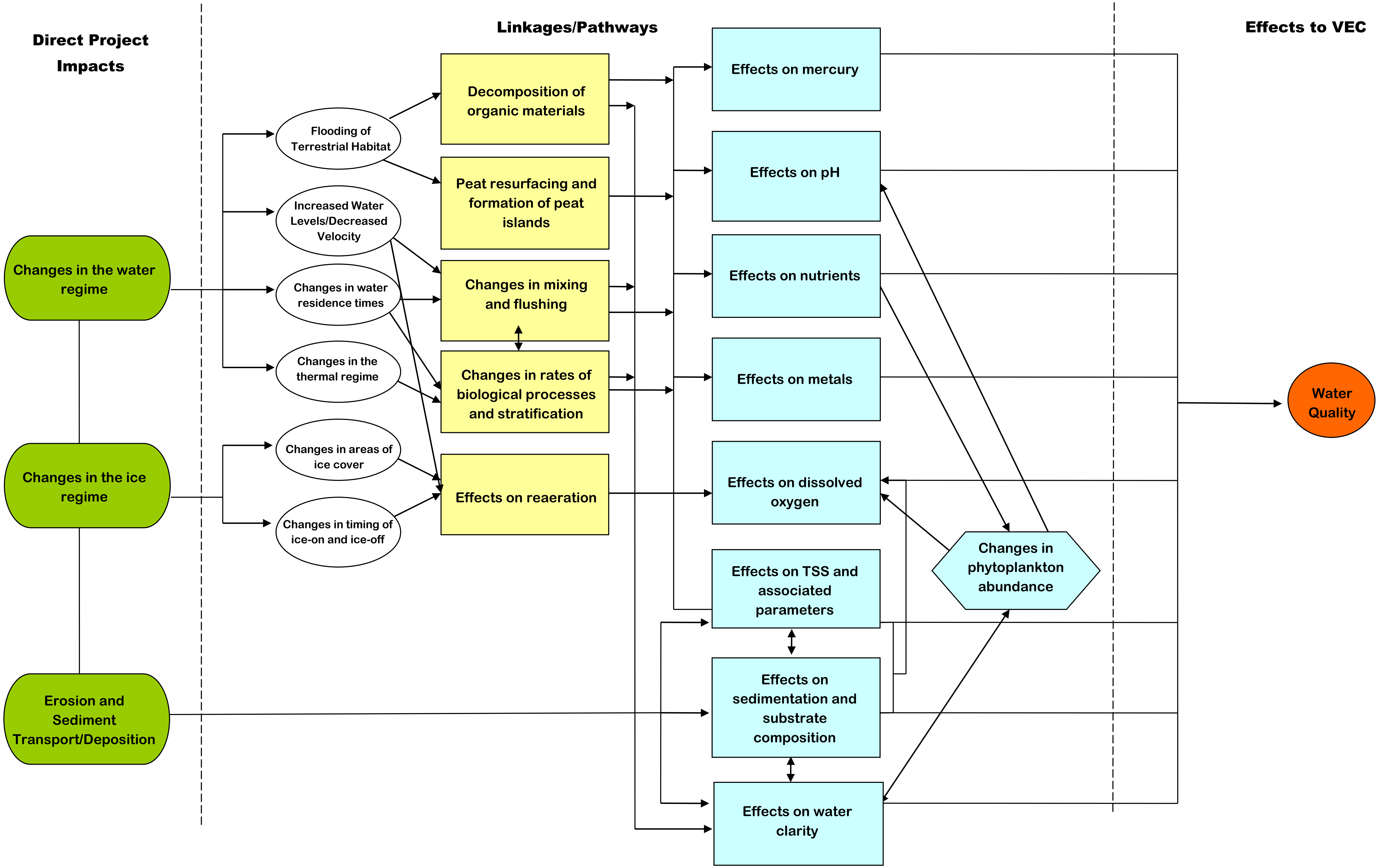

Figure 2-16: Linkages between direct and indirect project impacts and pathways of effects to water quality: Keeyask Generating Station operation period

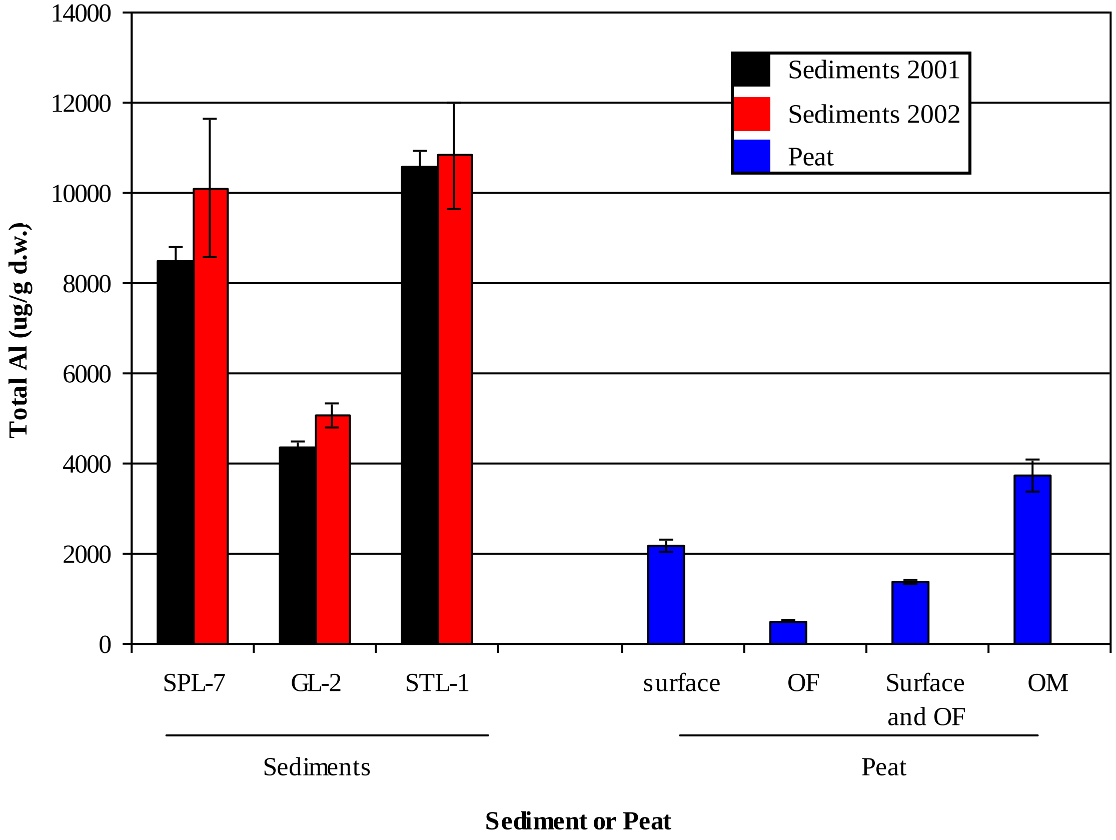

Figure 2-17: Mean±standard error of aluminum measured in sediments and peat samples collected from the study area. There are no sediment quality guidelines for aluminum

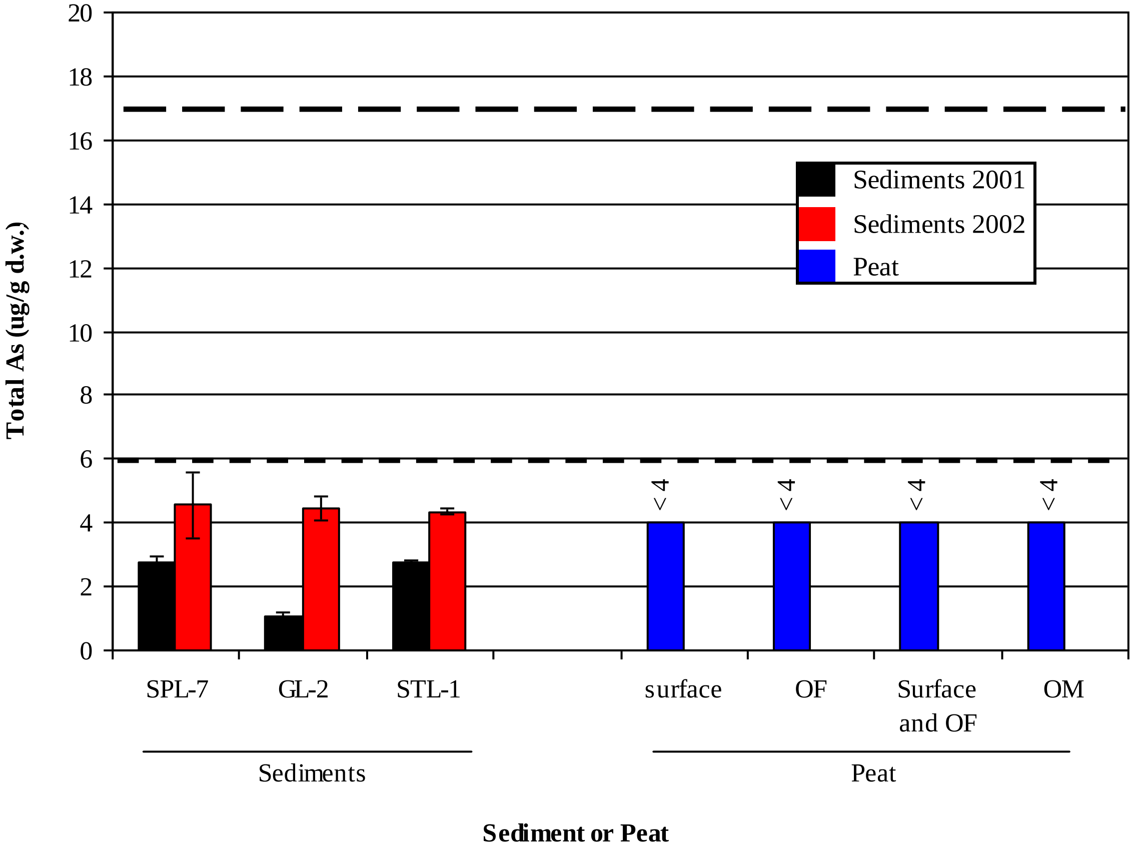

Figure 2-18: **Mean±standard error of arsenic measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life. Samples indicated with a number were reported as less than the indicated number**

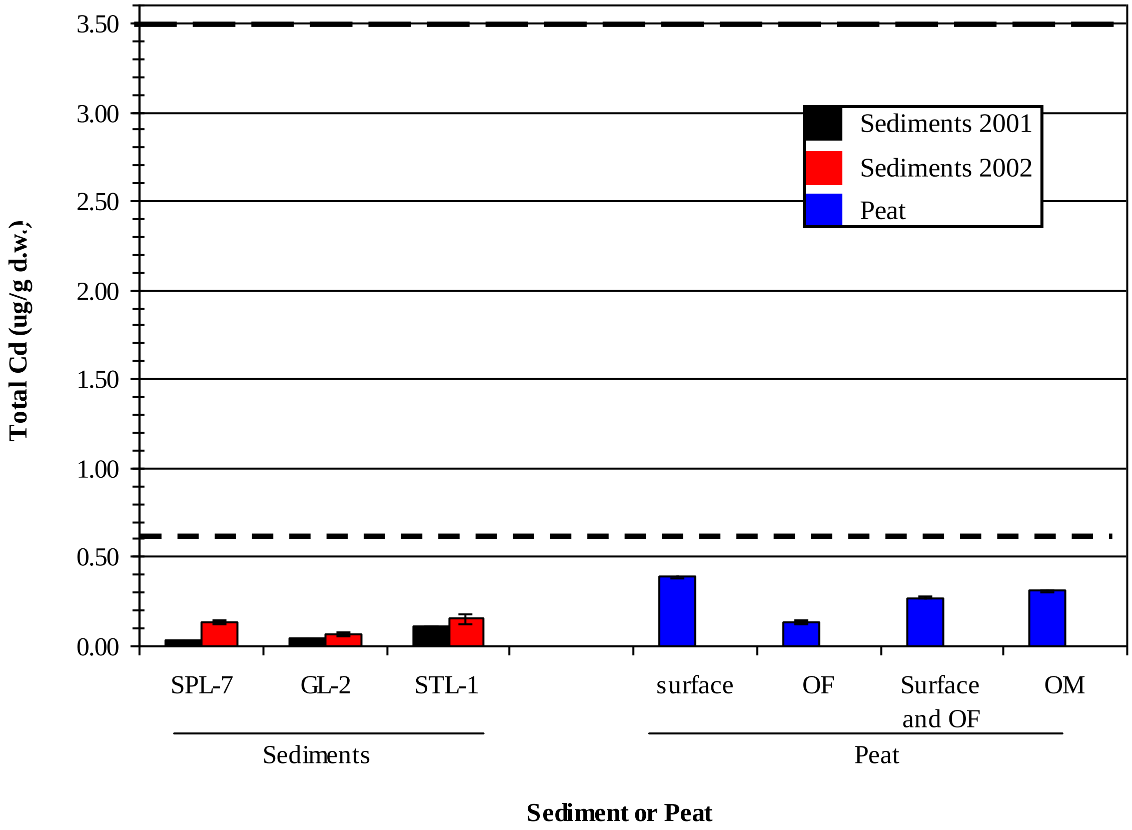

Figure 2-19: **Mean±standard error of cadmium measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life**

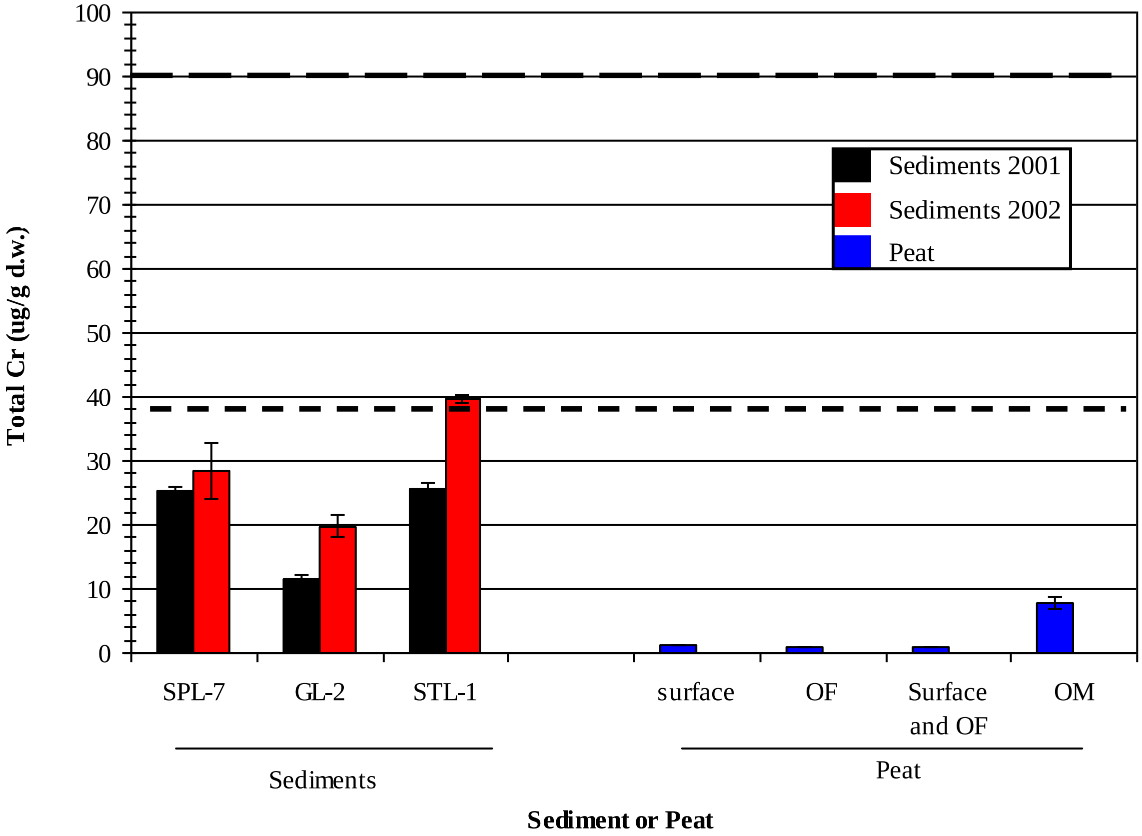

Figure 2-20: Mean±standard error of chromium measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life

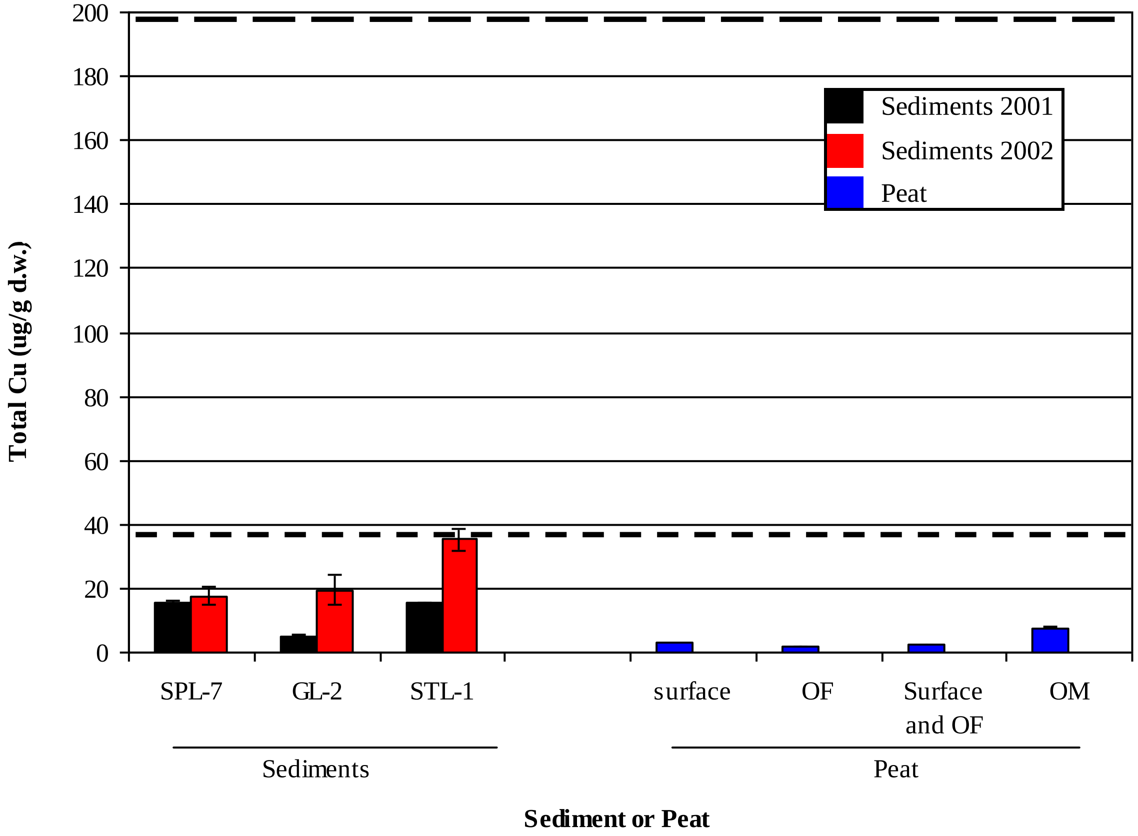

Figure 2-21: Mean±standard error of copper measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life

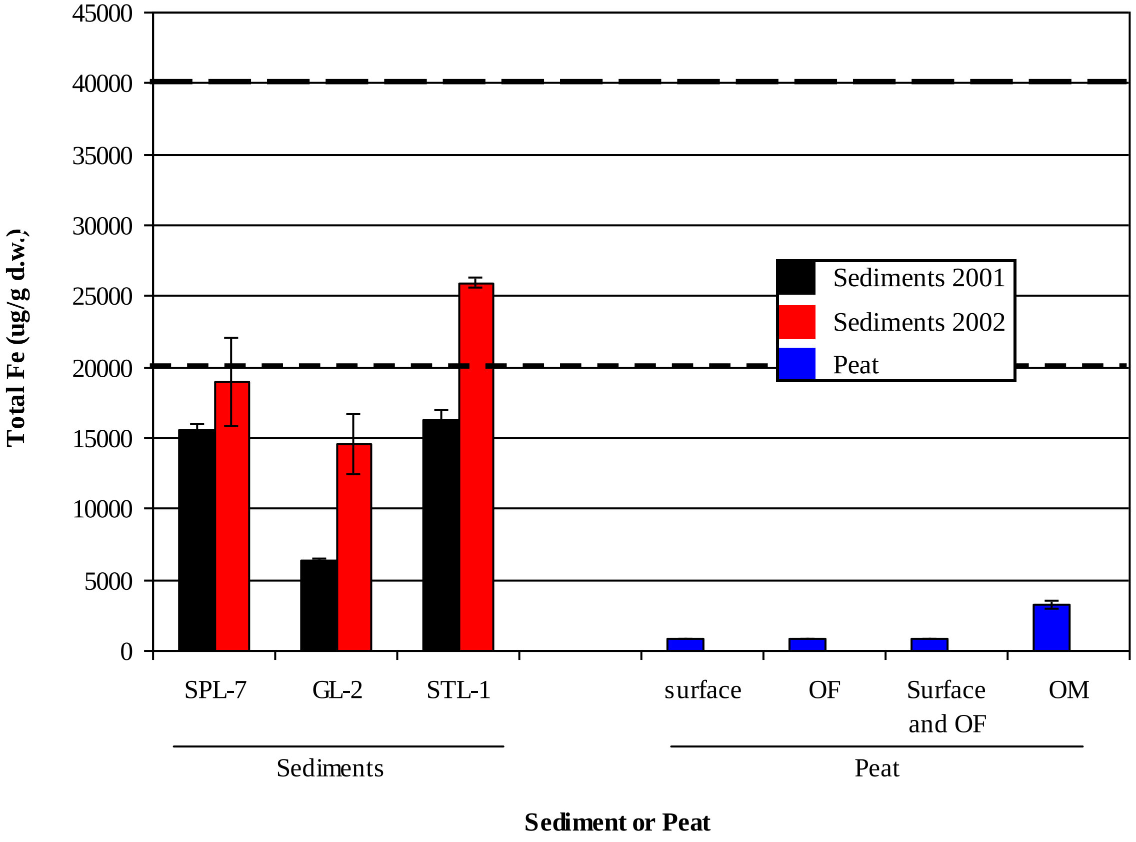

Figure 2-22: Mean±standard error of iron measured in sediments and peat samples collected from the study area. Dashed lines indicate the Ontario lowest effect level (lower) and the severe effect level (upper) for the protection of aquatic life

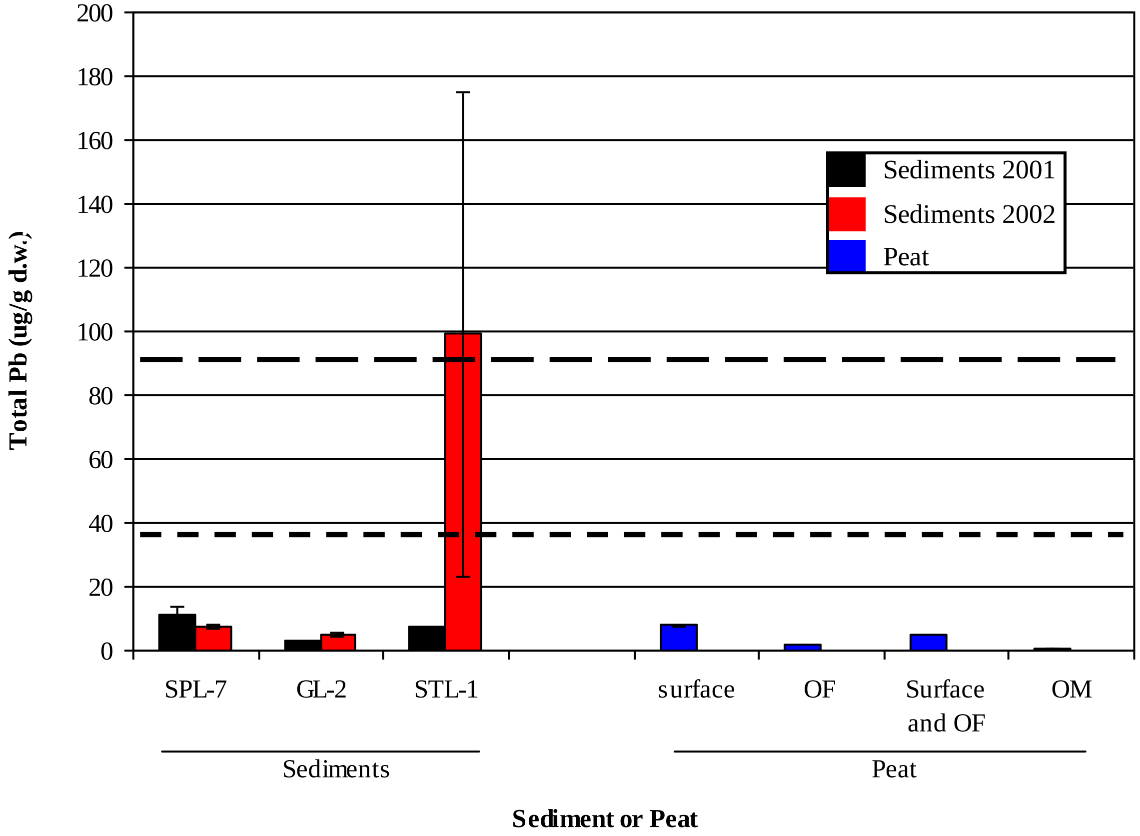

Figure 2-23: **Mean±standard error of lead measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life**

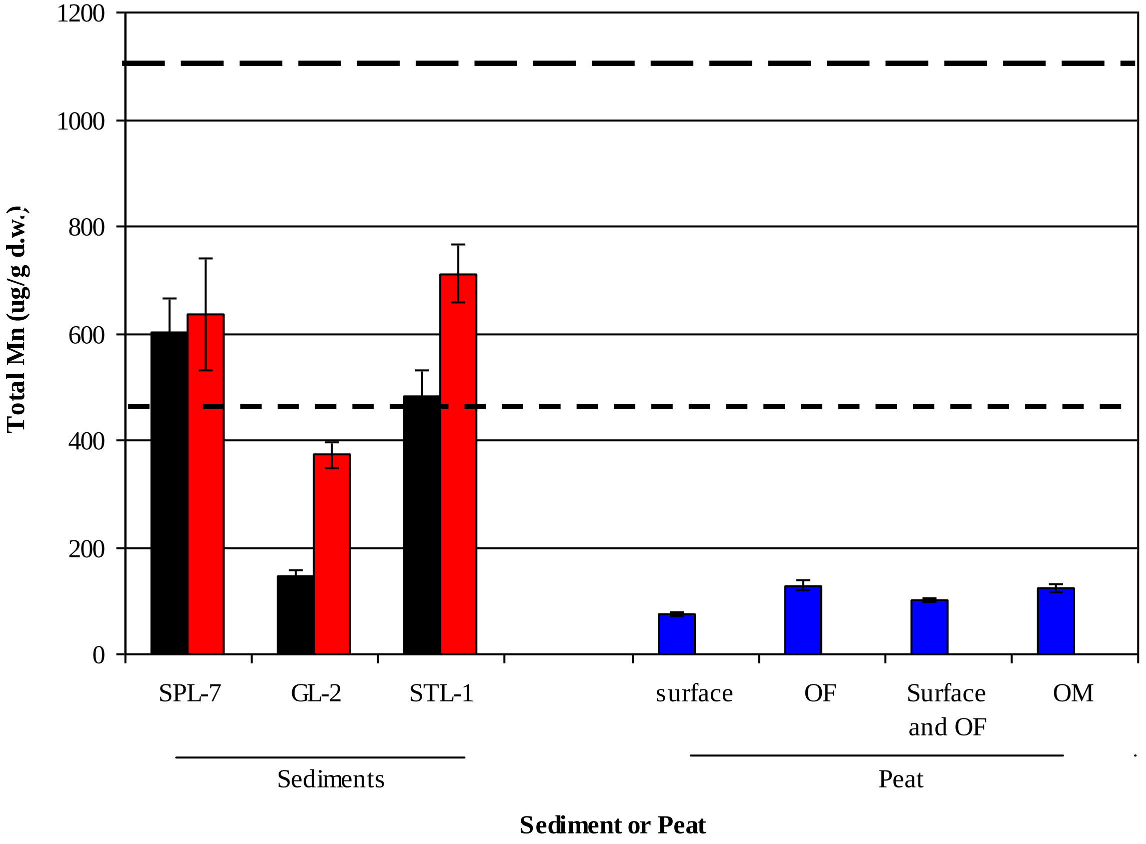

Figure 2-24: **Mean±standard error of manganese measured in sediments and peat samples collected from the study area. Dashed lines indicate the Ontario lowest effect level (lower) and the severe effect level (upper) for the protection of aquatic life**

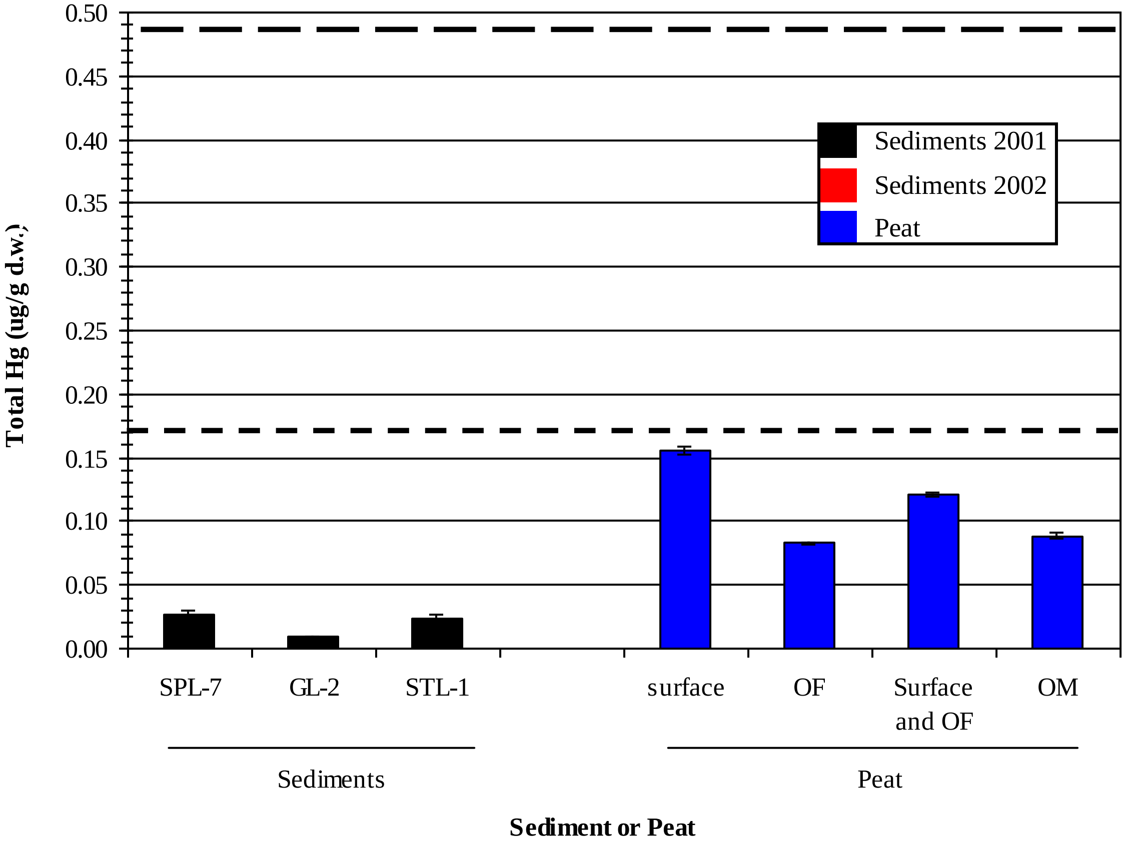

Figure 2-25: **Mean±standard error of mercury measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life**

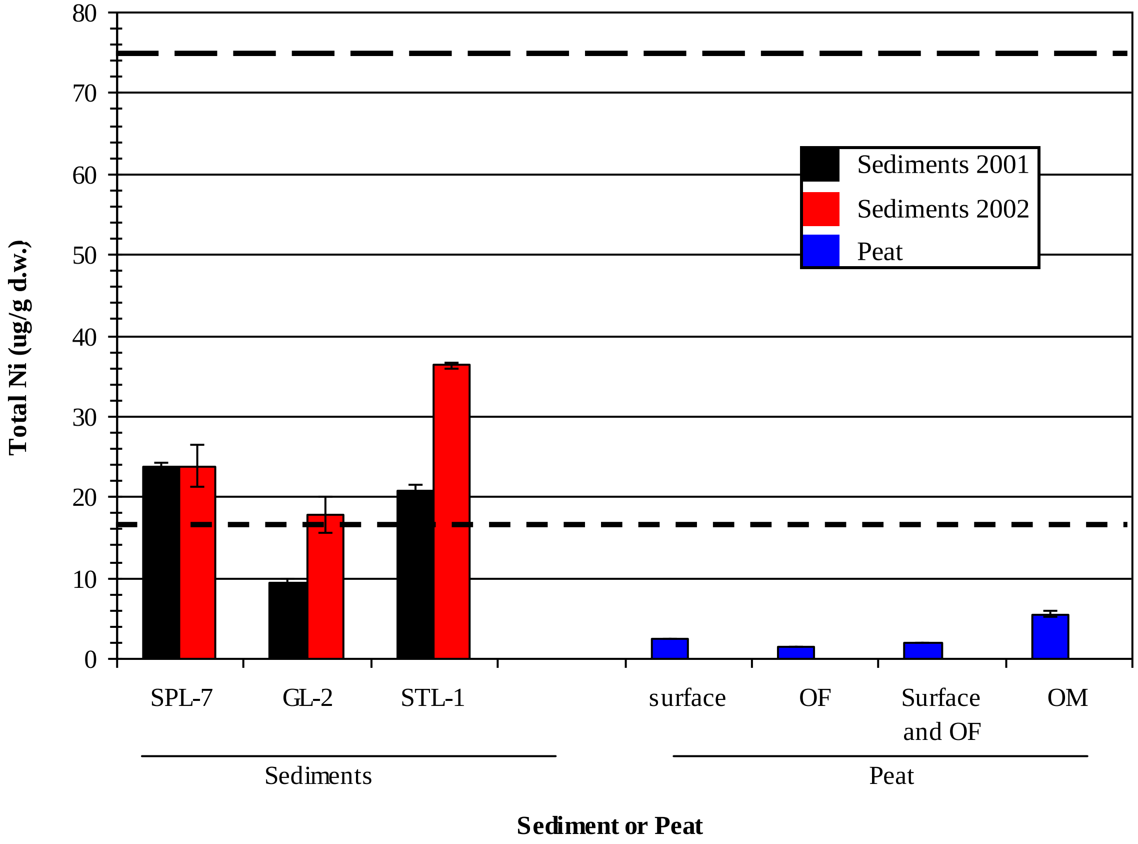

Figure 2-26: **Mean±standard error of nickel measured in sediments and peat samples collected from the study area. Dashed lines indicate the Ontario lowest effect level (lower) and the severe effect level (upper) for the protection of aquatic life**

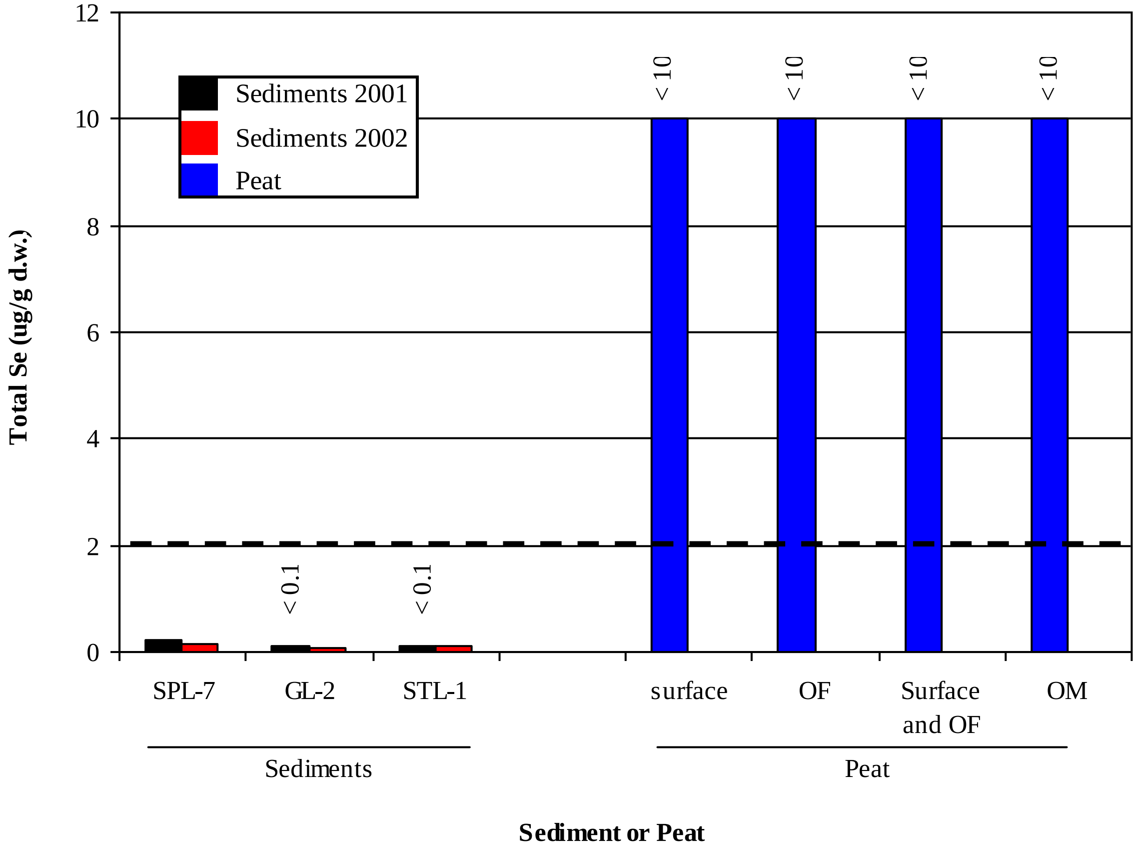

Figure 2-27: Mean±standard error of selenium measured in sediments and peat samples collected from the study area. The dashed line indicates the British Columbia sediment quality guideline for the protection of aquatic life. Numbers represent means that were less than the detection limits indicated

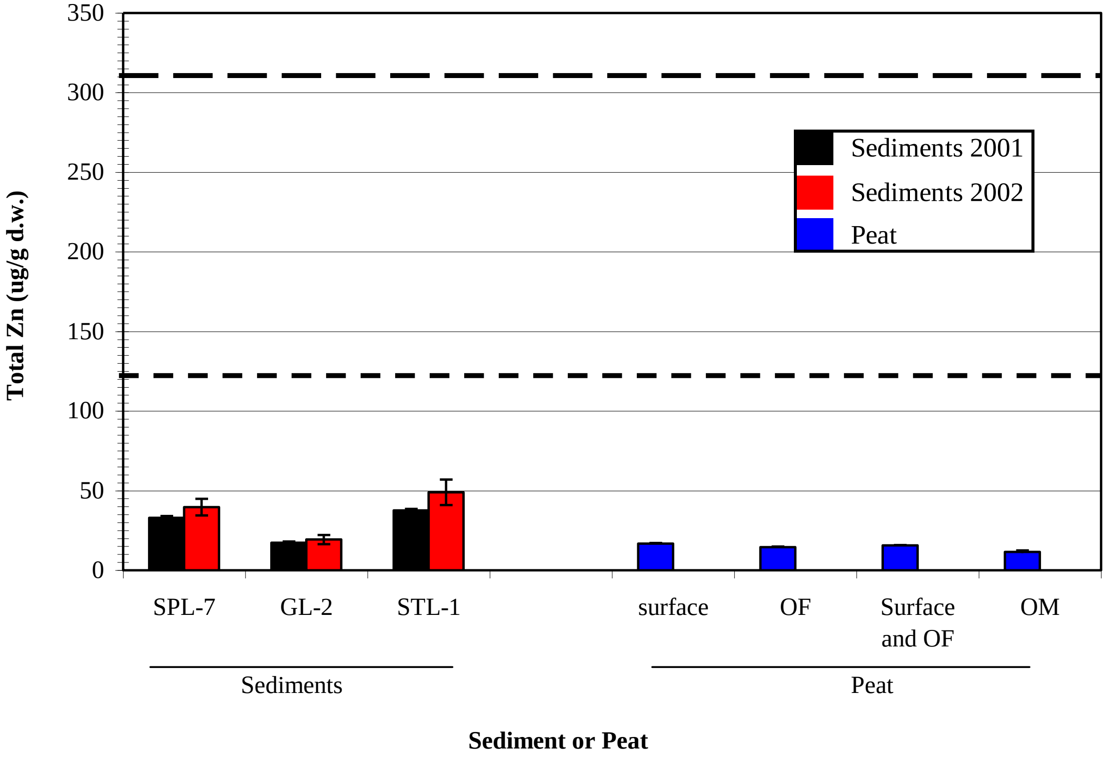

Figure 2-28: Mean±standard error of zinc measured in sediments and peat samples collected from the study area. Dashed lines indicate the Manitoba sediment quality guideline (lower) and the probable effect level (upper) for the protection of aquatic life

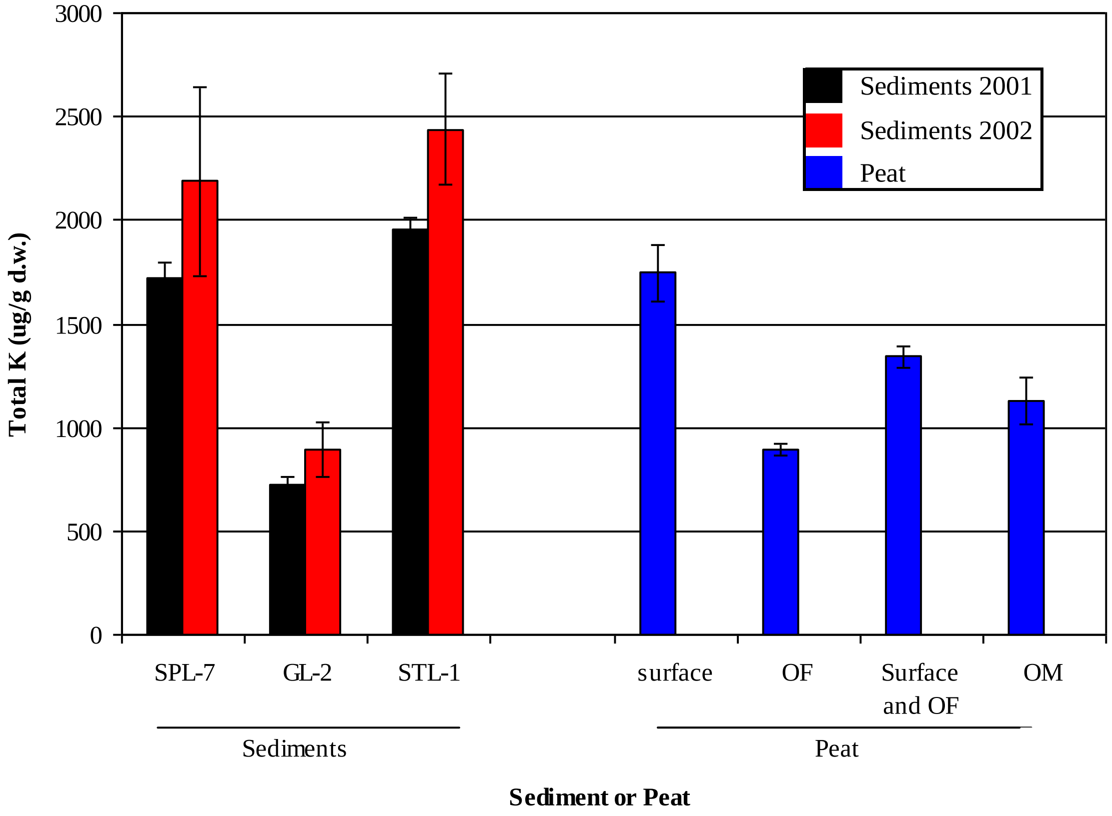

Figure 2-29: Mean±standard error of potassium measured in sediments and peat samples collected from the study area. There are no Manitoba sediment quality guidelines for the protection of aquatic life

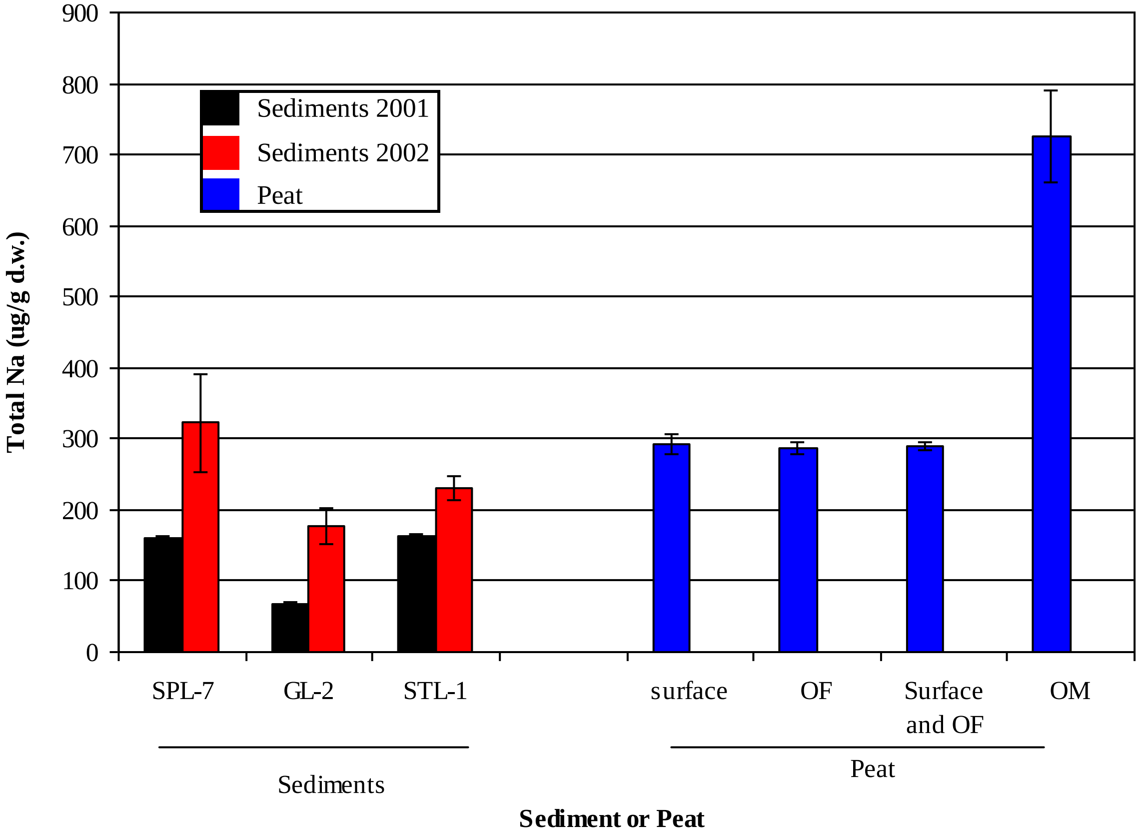

Figure 2-30: Mean±standard error of sodium measured in sediments and peat samples collected from the study area. There are no Manitoba sediment quality guidelines for the protection of aquatic life